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Complex Constructivism: A Theoretical Model of Complexity and Cognition

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Education has long been driven by its metaphors for teaching and learning. These metaphors have influenced both educational research and educational practice. Complexity and constructivism are two theories that provide functional and robust metaphors. Complexity provides a metaphor for the structure of myriad phenomena, while constructivism provides a metaphor for learning. In the synthesis of these two powerful metaphors lies a new metaphor—complex constructivism. The reality of complex constructivism is one in which the non-linear, adaptive, and constructive nature of learning is embraced. Complex constructivism views learning as the active construction and adaptation of one's internal models of reality based on the interaction between oneself and one's environment (including other persons), such that the functioning of one's internal models exceeds the sum of the models' components.

Education has long been driven by its metaphors for teaching and learning. These metaphors have influenced both educational research and educational practice (Leary, 1990). Since the late 1800s, three metaphors have dominated education: (a) learning as the acquisition of stimulus-response pairs (behaviorism), (b) learning as the processing of information (information processing), and (c) learning as the construction of knowledge (constructivism). Currently, there is an opportunity within education to examine the essentials of a new metaphor: learning as self-organized adaptation based in complexity theory (Brown, 2008).

These changes in explanatory metaphors have resulted from, and have allowed for, new insights concerning the nature of learning and knowledge. As researchers began to see that complex learning was difficult to explain using complicated chains of Stimulus → Response (S → R) pairs, and as the computer began to enter the academic consciousness, information processing theory emerged to explain how mental structures affect behavior. Then, after decades of productive research—that continues today—into the components of memory and cognition, it became apparent that context and culture influenced the representation of these components, and constructivism emerged to explain personal and cultural knowledge, meaning, and reality. However, as these new metaphors have emerged, one perspective has remained constant, the idea that learning involves parts, wholes, and adaptation. For behaviorism and information processing, the part-whole relationship is such that the whole can be predicted from the understanding of its parts. For the behaviorists, the component parts are S → R pairs, while for information processing theorists the component parts are memory structures. For constructivists, the component parts are experiences; however, constructivists recognize that the global behavior of an individual is not directly predictable through the understanding of an individual's experiences (Hacking, 1999; Tobias & Duffy, 2009).

In complexity theory—as in behaviorism, information processing, and constructivism—component parts are important. However, in complexity theory, what constitutes a "part," or an *agent*, depends on the level from which one views the learning process. An agent could be a neuron, a neuronal group, an experience, an individual, or a group of individuals. What is of importance, regarding agents, are not the agents themselves, but rather, the interaction of these agents with each other (Holland, 1995). As with constructivism, a complexity perspective recognizes the difficulty in predicting global behavior from an understanding of the parts (Guanglu, 2012; Waldrop, 1992). This complexity-based alternative perspective to understanding the whole, by understanding its parts, is to understand the whole by understanding the *interaction* of its parts (Cilliers, 2010; Lewin, 1992).

What follows is designed to (a) introduce the essential elements of a complexity-based view of learning, (b) demonstrate that the current emphasis in education on constructivism is compatible with a new perspective on education using complexity theory, and (c) discuss how complexity theory may expand our view of the learning process. These aims will be addressed through the presentation of a generic constructivist model, a generic complexity model, the development of a hybrid complex-constructivist model, and a discussion of the usefulness of a complex-constructivist view of learning.

Constructivism

Constructivism is generally the approach that learners construct their own knowledge from interpreting their experiences. Fosnot (1996) provided a more eloquent and inclusive definition:

> Learning from this perspective is viewed as a self-regulatory process of struggling with the conflict between existing personal models of the world and discrepant new insights, constructing new representations and models of reality as a human meaning-making venture with culturally developed tools and symbols, and further negotiating such meaning through cooperative social activity, discourse, and debate. (p. ix)

It is this combination of learner autonomy and holistic perspective that has thrust constructivism to the forefront of learning science and education. Learner autonomy is the concept that learners are active participants in the learning process and ultimately responsible for their own learning. This holistic perspective is a non-reductionist approach that emphasizes learning in context.

The integration of learner autonomy and holistic perspective places constructivism at the nexus of psychology and philosophy. A foundational issue in this psychological and philosophical nexus is the role of epistemology; that is, what is the nature of knowledge and how does the knower come to know (Doolittle & Hicks, 2003; Ernst, 1995). From this perch, von Glasersfeld (1984, 1995, 1996) and Doolittle and Hicks (2003) cited the pillars of constructivist epistemology as:

- Knowledge construction is an individually and socially active process.
- This active process of constructing knowledge is adaptive in that the end result is to make one's thoughts and behaviors more effective relative to achieving one's goals.
- Understanding of one's experience is a function of individual and social interpretation of one's experience.

These pillars, while illuminating, allow for great variability in what is typically called "constructivism" (Phillips, 1995; Prawat, 1996). Moshman (1982) helped to define this variability through a continuum of constructivism. Moshman (1982) defined the poles of this continuum as *exogenous constructivism*, *dialectical constructivism*, and *endogenous constructivism*, what would more typically be called today *trivial constructivism*, *social constructivism*, and *radical constructivism*. This constructivist continuum provides a rationale for the placement of other types of constructivism (see Figure 1).

Constructivist Models

Trivial constructivism emphasizes the external nature of knowledge (see Figure 2). Knowledge is seen as the internalization and reconstruction of external reality. Learning or knowledge acquisition is the process of building accurate internal models or representations of external structures in the "real" world. This view presupposes that reality is knowable. Trivial constructivism is often erroneously associated with information processing and its component processes, including schemata, declarative and procedural knowledge, and propositional-networks (Derry, 1996). Trivial constructivism often serves the role of "straw man" against which constructivism, writ large, is compared.

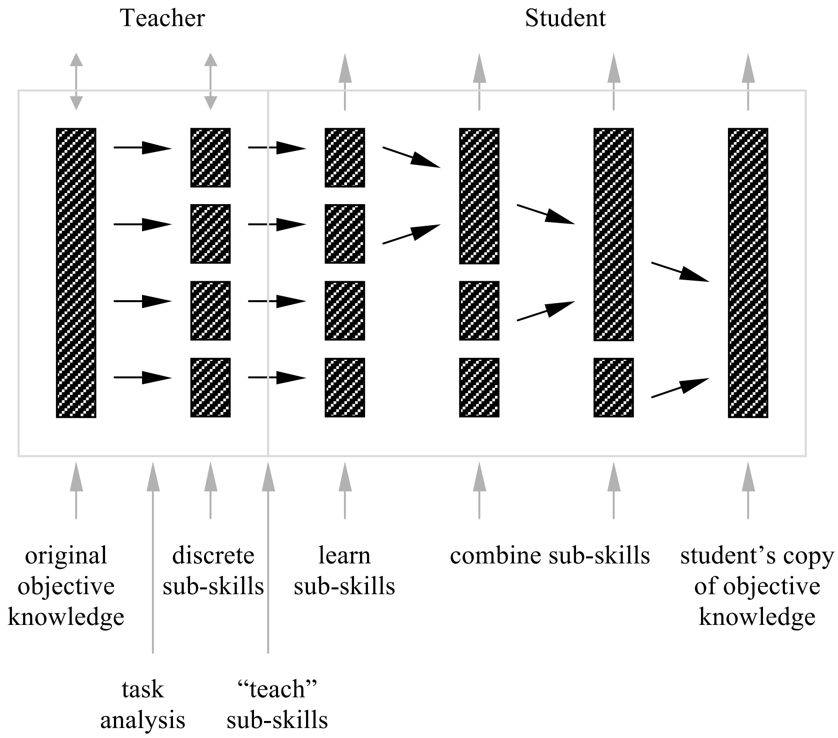
In Figure 2, the dark rectangle on the left represents some aspect of knowable reality that is to be constructed by the student. This knowledge is subdivided into discrete sub-skills by the teacher who then transmits this knowledge to the student. A successful teaching/learning event results when the student, after this transmission experience, has constructed an accurate representation (the dark rectangle on the right) of the original, knowable knowledge.

Trivial constructivism represents one extreme of the constructivist continuum, while radical constructivism represents the other extreme. Radical constructivism emphasizes the internal nature of knowledge (see Figure 3) and is based on the theoretical foundation of Piaget (1973, 1977). Knowledge is constructed from both external experiences and earlier mental structures. Learning or knowledge acquisition is the reconstruction and reorganization of old knowledge structures in light of new experiences. Thus, knowledge is not an accurate

Figure 1
A Constructivist Continuum

Trivial Constructivism	Social Constructivism	Radical Constructivism
◄	———	►
Exogenous Constructivism	Dialectical Constructivism	Endogenous Constructivism
Cognitive Constructivism	Social Constructionism	Schema-based Constructivism
Information Processing Constructivism	Sociocultural Constructivism	Emancipatory Constructivism
Psychological Constructivism	Symbolic Interactionist Constructivism	Developmental Constructivism
Naïve Constructivism	Idea-based Social Constructivism	Psychological Constructivism

Figure 2
Cognitive Constructivism



representation of external reality, but rather is an internally coherent and coordinated collection of processes and structures that provide for adaptive behavior. This view presupposes that reality is not knowable (von Glasersfeld, 1995).

According to Piaget (1973), cognitive development is the result of invariant changes in internal mental structures, characterized by a continuum of qualitatively different reasoning skills, and caused by integrating and extending previous levels of cognitive development into new knowledge/cognitive levels. Piaget emphasized the role of discovery and exploration as activities or experiences that fostered these changes in mental structure.

In Figure 3, derived from both Piaget (1970, 1973, 1977) and von Glasersfeld (1995), an individual experiences an event and seeks to understand that event through in terms of what they already know (assimilation) and what they have already experiences (re-presentation). This initial understanding leads to a goal directed response, either cognitive or behavioral. If the response is satisfactory then the initial understanding is reinforced, but if the response does not yield satisfactory results then the individual must reorganize or modify their initial understanding to better account for the unsatisfactory results. This process of event interpretation → cognitive/behavioral action → expected/unexpected results → verifying/reorganizing understanding constitutes an adaptive process designed to make one's understandings and subsequent actions more viable.

Finally, social constructivism lies somewhere between the transmission of knowable reality of the trivial constructivists, and the interpretation of personally viable reality of the radical constructivists. Social constructivism emphasizes the interactional nature of knowledge (see Figure 4). Knowledge is the result of the *interaction* between the learner and the environment, including other learners. Learning or knowledge acquisition is the process of building internal models or representations of external structures as filtered through and influenced by one's beliefs, culture, prior experiences, and language, based on interactions with others, direct instruction, and modeling. This view presupposes that "reality" is not knowable.

According to Vygotsky (1978), cognitive development is based on a student's ability to learn socially relevant tools (e.g., hammers, pencils, computers) and culturally based signs (e.g., language, writing, number systems) through interactions with other students and adults who socialize them into their culture. These culturally mediated activities provide social experiences that are internalized and which later

Figure 3
Radical Constructivism

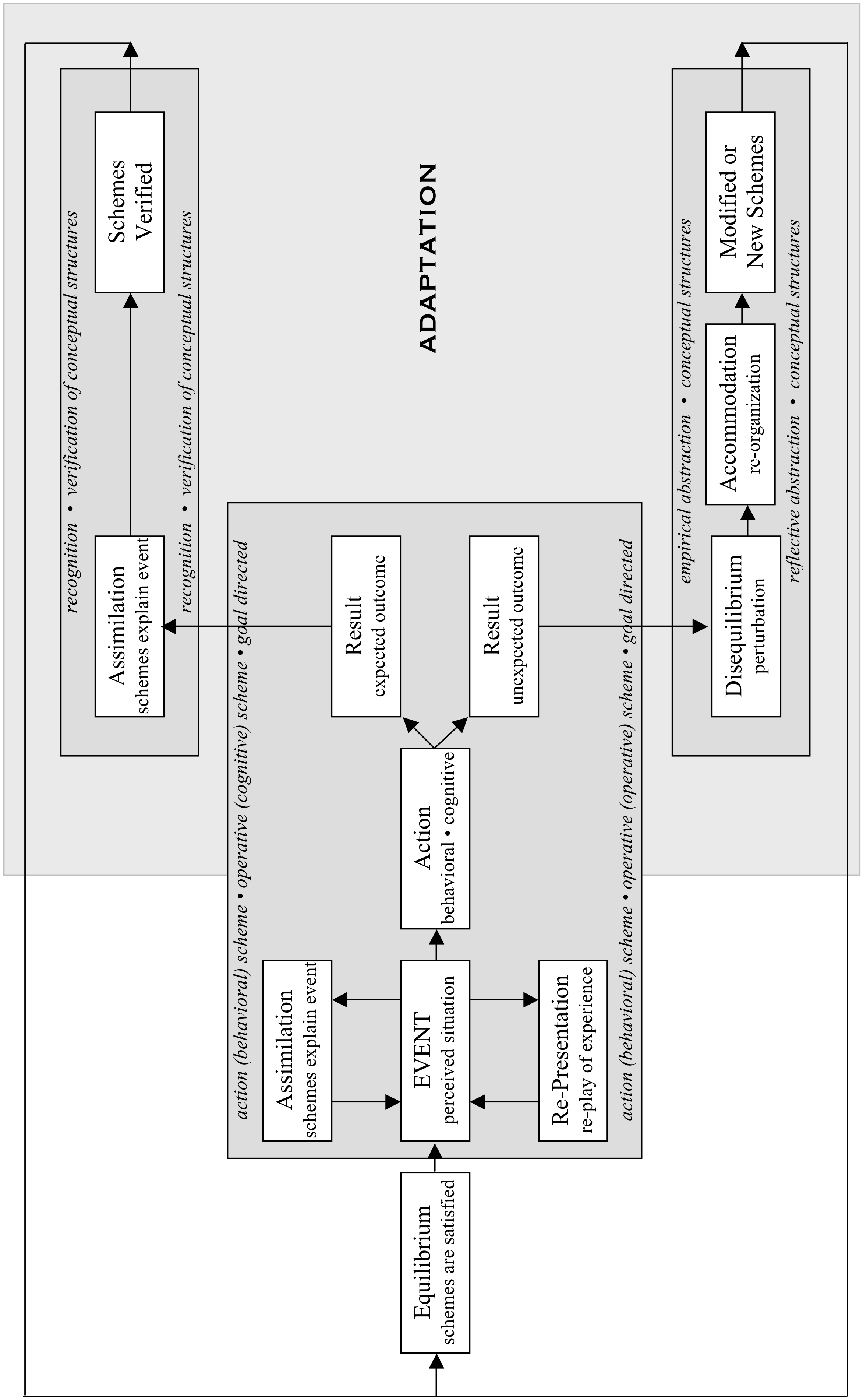
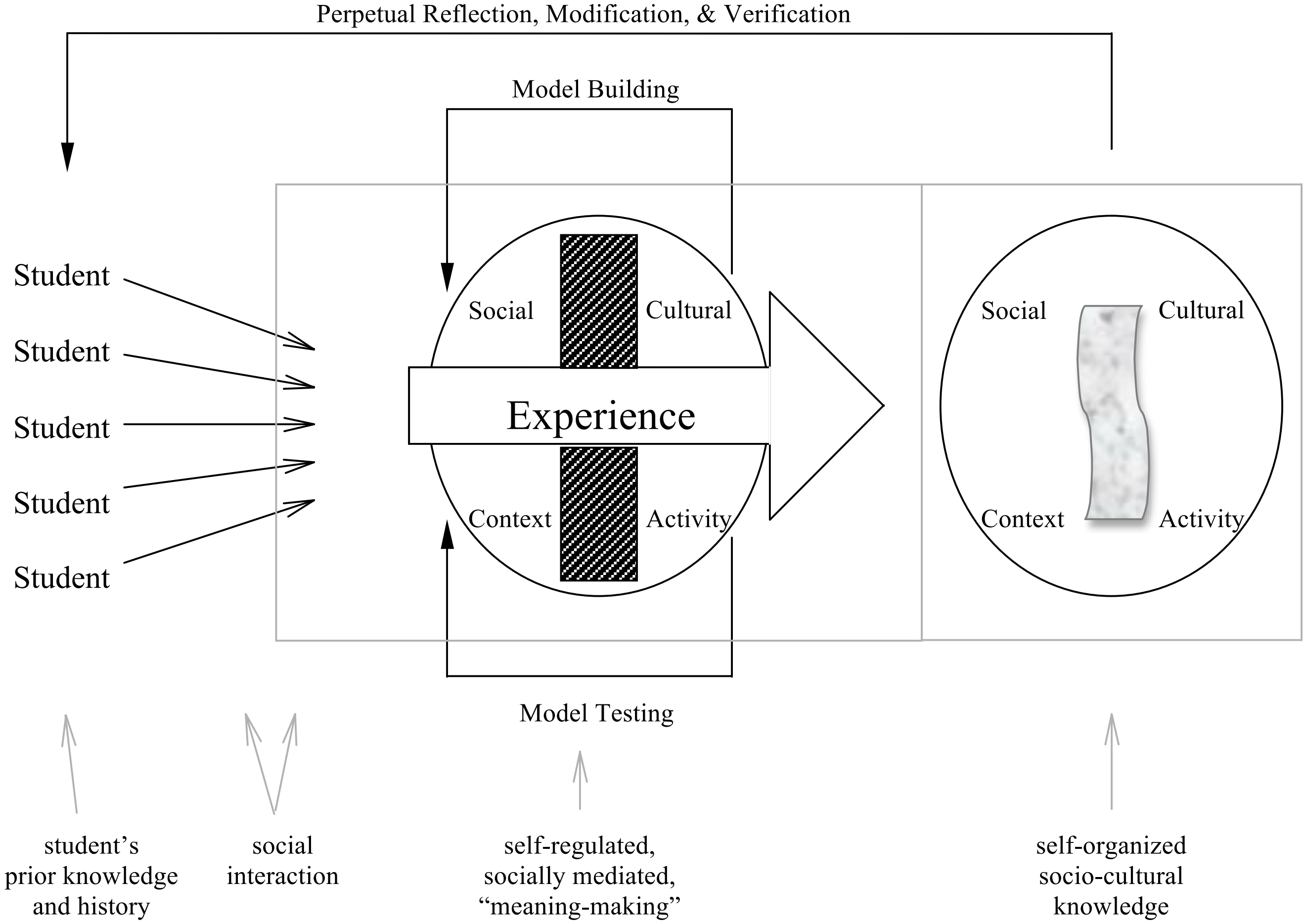


Figure 4
Social Constructivism



become a part of the individual's mental functioning. Thus, knowledge is the result of social experience, influenced by one's socio-cultural history, and resulting in a modified representation of experience.

In Figure 4, students interact with knowledge (dark rectangle) within a socio-cultural environment. This external social experience results in the formation of internal mental structures (models) that are influenced by the presence of social, cultural, contextual, and activity-based factors. The student does not acquire an exact representation of this knowledge (light rectangle), but rather, a personal interpretation of the external knowledge. The viability of this newly constructed knowledge will be based on the student's prior knowledge and the impact of the social, cultural, contextual, and activity-based factors.

Constructivist Learning Principles

Constructivism is a broad theory that lends itself to many interpretations. Under the guise of constructivism lay many theories of learning, including situated cognition, anchored instruction, cooperative learning, inquiry and problem-based learning, generative learning, exploratory learning, reciprocal teaching, cognitive apprenticeships, and information processing. Yet, from these constructivist theories and the constructivist models (Figures 2-4), Doolittle and Hicks (2003) have derived the following principles of learning:

1. The construction of knowledge and the making of meaning are individually and social active processes.
2. The construction of knowledge involves social mediation within cultural contexts.
3. The construction of knowledge is fostered by authentic and real-world environments.
4. The construction of knowledge takes place within the framework of the learner's prior knowledge and experience.

5. The construction of knowledge is integrated more deeply by engaging in multiple perspective and representations of content, skills, and social realms.
6. The construction of knowledge is fostered by students becoming self-regulated, self-mediated, and self-aware.

These principles encompass the essence of constructivism, that is, learning as the adaptive and self-organized construction of knowledge that is a function of both one's prior knowledge and experience, and one's current socio-cultural activity. This perspective on learning reflects the complexity of learning as involving adaptation, self-organization, interaction, and history.

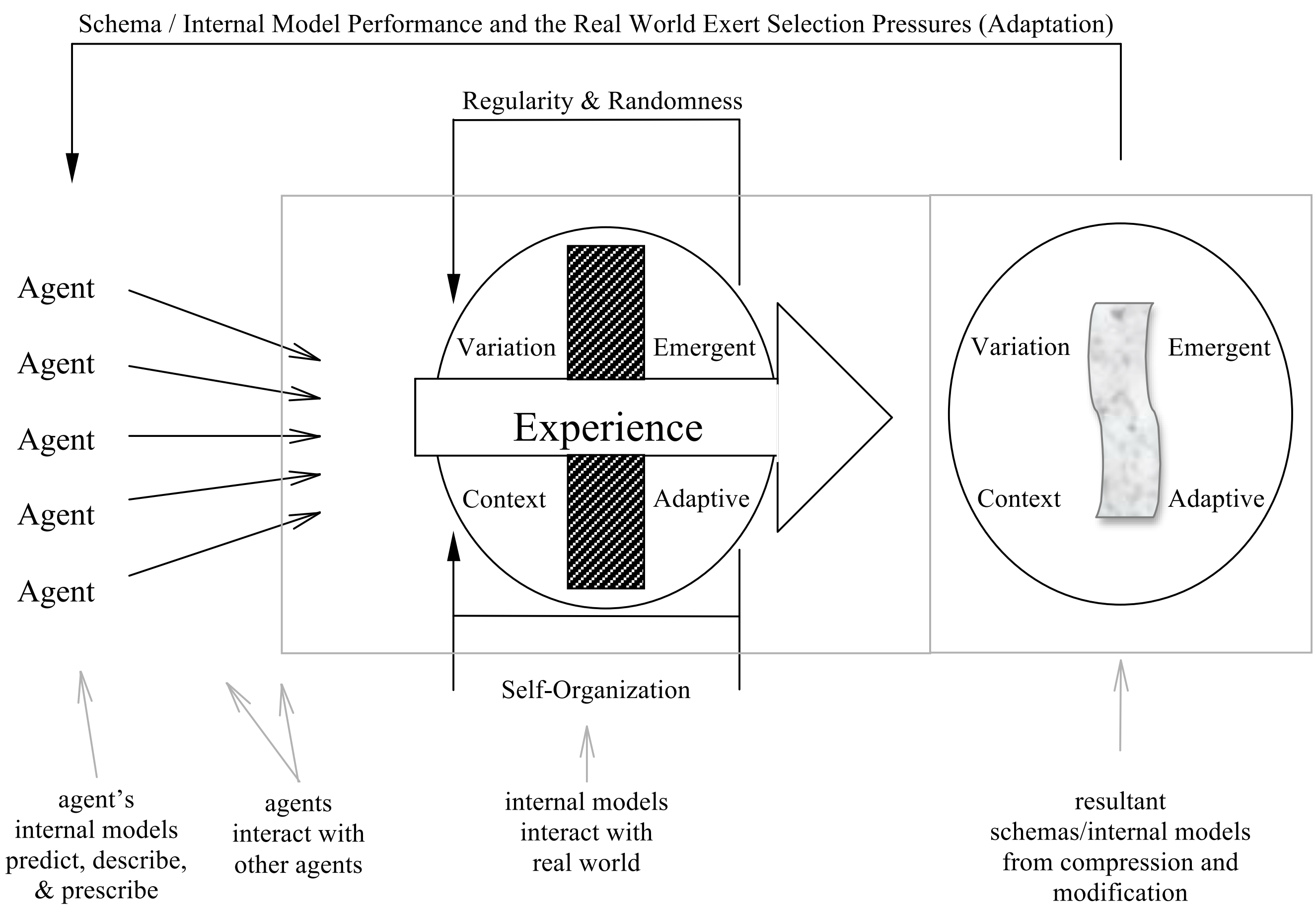
Complexity Theory and Complex Adaptive Systems

The theory of complexity is not a theory of learning, memory, and cognition, per se; complexity is a broad-based theory concerning the evolution and functioning of non-linear systems that may be applied in many domains (e.g., evolution, immunology, economics), including learning, memory, and cognition (Coveney & Highfield, 1995; Hase & Kenyon, 2013; Morowitz & Singer, 1995). That said, new concepts and a new vocabulary are necessary to understand the essential aspects of a complexity perspective. A list of basic complexity theory terms includes adaptation, agents, complexity or complex adaptive systems, emergence, fitness, hierarchy, internal models, non-linearity, regularity and randomness, schemas, selection and selection pressures, self-organization, systems, and system dynamics. These terms and complexity theory, in general, are addressed using a school as an example of a complex system and Figure 5 as a conceptual model.

Complex Systems

The study of complexity involves the study of complex systems that are inherently non-linear, open, and far from equilibrium (Thelen & Smith, 1994). A *non-linear system* is unpredictable, that is, if one is familiar with all the components of the system, one is

Figure 5
Complexity Model



still unable to determine exactly what will happen next (e.g., weather, human behavior, ecology). In addition, in a non-linear system the whole is greater than the sum (or average) of its parts (Holland, 1995). While complex systems are unpredictable and non-linear, they are also open. An *open-system* is a system that needs and receives energy to maintain its order. This maintenance of order places the system in a state that is *far from equilibrium*, equilibrium being the degenerative state that the system would inhabit if there were no influx of energy. Thus, a complex system is greater than the sum of its parts but requires energy to maintain this greater order. According to Kelso (1995),

> These are called open, nonequilibrium systems: open in the sense that they can interact with their environment, exchanging energy, matter or information with their surrounds; and nonequilibrium, in the sense that without such sources they cannot maintain their structure or function. (p. 4)

For example, a school is a non-linear, open, and far from equilibrium system (Larsson & Dahlin, 2012). The school is non-linear because even if one was to know the position and direction of movement of all the students, teachers, staff, and administrators at a given point in time, one would not be able to predict what would happen next. Students that were walking to the library may decide to go to their lockers instead and a teacher may suddenly decide to give a pop-quiz. Also, the activity in the school is far greater than the sum of the individual students, teachers, and administrators. As students, teachers, staff, and administrators begin to collaborate, the whole becomes greater than its parts. Student and teacher teams emerge, interacting students learn more than they were capable of learning on their own, and special programs are formed to assist students with their special needs. All of this far from equilibrium activity and learning is made possible through an influx of energy into the school (an open-system), energy in the form of students, materials, food, and money. If there were not this influx of energy, or resources, the school would deteriorate into a state of disrepair and disorder.

A non-linear, open, and far from equilibrium *system* is a group of interdependent elements, or agents, that interact to form a composite whole, while *system dynamics* refers to the feedback structures, methods, and outcomes of these interactions (Brodnick & Krafft, 1997). A complex system is composed of *agents*, individual active elements of a system that possess an internal state comprised of internal models, rules, and strategies that influence and guide the agent's behavior (Holland, 1995). A group of common agents is an *agent type*.

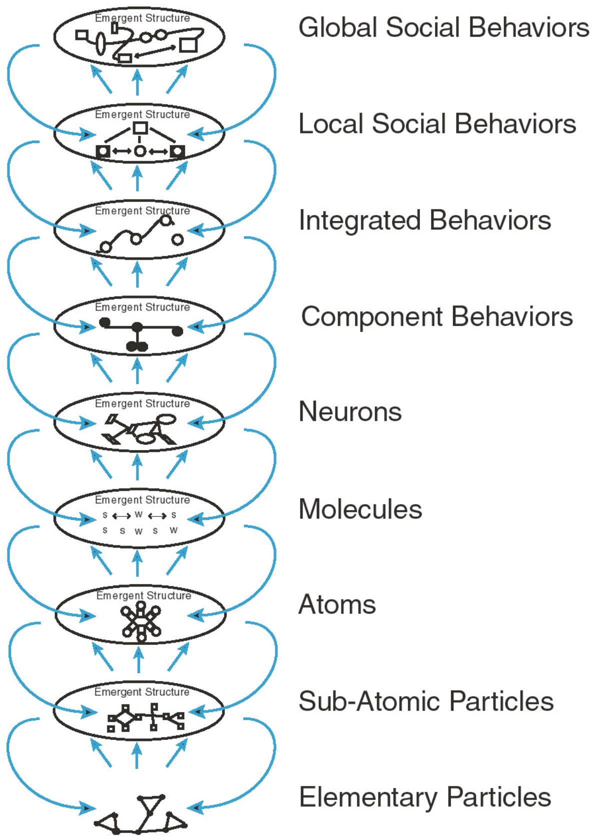
For instance, a school is a system that is comprised of several agents and agent types, such as students (a student is an agent, all of the students would constitute an agent type), teachers, staff, and administrators. The system dynamics involving the interaction of the students, teachers, staff, and administrators, is governed by explicit and implicit rules of conduct, order, need, and expectation.

In addition, each agent functions through the use of *internal models* or *schemas* (Gell-Mann, 1995; Holland, 1995). An internal model, or schema, is created or modified as the agent gains experience. As the agent gains experience, the agent abstracts the *regularity* from the *randomness* within the experience and begins to form internal models that describe these regularities. The agent may construct several internal models or schemas of a given experience, each internal model or schema providing a potential explanation of the experience. The process of changing recognized patterns of regularity into internal models occurs through *compression*. Compression results in abstractions or generalizations of experience, not a verbatim record. Often, internal models or schemas are described by a set of rules (see Holland, 1995, 1998). These internal models are then used by the agents to describe current events or behaviors, predict future events or behaviors, and prescribe subsequence behavior.

Continuing the school example, each student, teacher, staff, and administrator has several internal models or schemas related to the school environment. A particular student, for example, will have internal models or schemas that relate to how she interacts with teachers, takes tests, or fits into the school social structure. This student, while having different internal models or schemas related to different topics, may also have more than one internal model or schema for the same topic. She may have several internal models or schemas of how to interact with teachers, such as a friend, as a subordinate, or as a mentor. This student will continually create and modify her internal models and schemas based on her continuing interaction with teachers. She may notice that the female teachers like to be referred to as "Ms." and not "Mrs.", and so she modifies her internal model or schema accordingly. This generalization, or compression, of addressing the female teachers as "Ms." will allow the student to anticipate the need to use the "Ms." title (prediction and prescription), and will provide a basis for understanding when a teacher is curt with her after she uses the title "Mrs." accidentally (description).

In a complex system, these interacting agents exist within a hierarchy of agents (see Figure 6; Lewin, 1992). Agents at one level of the hierarchy interact with each other, and other agent types, and through this interaction an emergent global structure (Lewin, 1992),

Figure 6
An Agent Hierarchy



or aggregate system of meta-agents or behavior, emerges (Holland, 1995). A meta-agent is an assembly of lower agents— "lower" and "higher" do not translate into "worse" and "better" or "less complex" and "more complex," lower and higher are used solely to represent differing levels and order of construction—that form a new agent at a higher level in the hierarchy (i.e., cells assemble to form organs, organs assemble to form organisms), while an aggregate behavior would be a behavior that is comprised of other more fundamental behaviors (e.g., playing basketball is comprised of walking, running, dribbling). These emergent global structures and meta-agents, upon forming, then feedback to the lower level agents to influence the lower level agents' interactions. An essential aspect of this process of lower level agents giving rise to higher level agents is that the nature and formation of the higher level agents is not predictable from an understanding of the individual behaviors of the lower level agents, a process known as *emergence* (Casti, 1994; Crutchfield, 1994; Holland, 1998). Emergence is an enigmatic process whereby fundamental agents produce surprising and unpredictable meta-agents or behaviors. These meta-agents or behaviors are said to emerge from the interaction and collective properties of the lower agents (e.g., clouds emerge from water vapor and heat, life emerges from DNA, mind emerges from neurons). According to Thelen and Smith (1994), "These emergent organizations are totally different from the elements that constitute the system, and the patterns cannot be predicted solely from the characteristics of the individual elements" (p. 54).

Within a school setting, the students, teachers, staff, and administrators give rise to a particular school behavior or setting, that is, the specific nature, atmosphere, and environment of the school. The presence and interaction of these students, teachers, staff, and administrators (i.e., agents) leads to the emergence of surprising and unpredictable school behaviors, such as racial tension, academic rigor, or drug acceptance or rejection. Emergence, in the case of academic rigor, may involve a school in which students consistently put forth effort, teachers continually challenge their students, and administrators actively support both the teachers and students. This academic rigor is not a function of any one student, teacher, staff, or administrator, but rather, this academic rigor is a function of the interaction between the students, teachers, staff, and administrators.

This process of emergence is deeply intertwined with the concept of self-organization. *Self-organization* refers to the spontaneous self-generation of order from within an open-system of agents (Capra, 1996; Kelso, 1995), or what Kauffman (1995) called "order for free." A fundamental component of self-organization is that order arises from within the interactions of the agents and is not imposed on the agents from some external force. Thus, as agents interact, they organize themselves according to local parameters and self-interest, and from this self-organization a more global or higher structure emerges. In this way, self-organization and emergence are inexorably linked. According to Jacobson (1997), "Self-organizing phenomena are inherently decentralized due to the local interactions of many individual agents, with order 'emerging' without centralized control structures" (p. 3).

Self-organization within the school example concerning academic rigor, might involve students meeting in study groups, teachers preparing academically challenging projects, and administrators purchasing extra equipment for students and teachers. These activities have not been organized outside of the school and imposed on the students, teachers, staff, and administrators; rather, the students, teachers, staff, and administrators have developed these activities themselves, to satisfy their own (agent-based) goals and needs. In addition, it is these self-organized activities that have led to the emergence of the academic rigor, and in turn, this academic rigor has influenced the further self-organization of activities, forming a feedback mechanism.

This process of self-organization ➔ emergence ➔ feedback forms the basis for selection pressure and adaptation (Gell-Mann, 1994). As agents interact with other agents and the environment, the agent's internal models and schemas self-organize and emerge. In this process, the agent's interactions with other agents and the environment serve as evaluations of the agent's internal models and schemas. If an agent repeatedly exhibits a behavior that is counter-productive, based on an internal model or schema, then the internal model or schema is modified, discarded, or ignored. If, however, the agent repeatedly exhibits a behavior that is productive, then the internal model or schema that is responsible is retained. Gell-Mann (1994) referred to this evaluative feedback, from instantiating internal models or schemas in the real world, as *selection pressure*; that is, the real world exerts pressure on the agent to select the internal model or schema that consistently produces favorable results. In a similar manner, from a Darwinian natural selection perspective, those agents that are able to generate and select effective internal models and schemas will be more likely to be selected for reproduction and survival. In addition, an agent that is capable of repeatedly selecting internal models and schemas that are favorable is considered *fit*, or to have *fitness*, in relation to the environment in which the agent exists. However, environments do not remain static, thus an agent's level of fitness is always in a state of flux. This state of flux requires the agent to continually monitor and modify its internal models and schemas as the environment changes, a process known as adaptation (Kauffman, 1993, 1995). *Adaptation* refers to changes in internal models or schemas that improve the performance (or fit) of the agent, whether that performance is reproduction, survival, money, or knowledge. Holland (1995), in defining adaptation in complex systems, stated, "Roughly, experience guides changes in the organism's structure so that as time passes the organism makes better use of its environment for its own ends. Here we expand the term's range to include learning and related processes" (p. 9).

Maintaining the school and academic rigor example, selection pressures for student performance might involve grades, college admission, parental approval, and peer approval. As a student uses various study strategies, and succeeds or fails, and as this student watches other students use various study strategies, and they succeed or fail, the student constructs internal models and schemas related to study strategies and which work and which do not work, under various conditions. Indeed, this student may experience both success and failure using the same study strategy for two different teachers, reflecting two different levels of fitness for the same strategy. At this point, the student needs to adapt to the environment by using the appropriate study strategy with the appropriate teacher. Thus, retaining internal models or schemas that are fit and modifying internal models or schemas that are less fit leads to adaptation and better overall performance.

In summary, complex systems are non-linear, open, and far from equilibrium systems that are comprised of interdependent agents whose interactions, based on internal models and schemas, lead to self-organized and emergent behaviors that have dynamic fitness levels in response to selection pressures exerted by changing environmental conditions, thus facilitating the need for adaptation in order to maintain effective performance.

Complexity Principles

This broad-based theory has been developed as an inter-disciplinary theory, crossing any and all domain boundaries. Given this inter-disciplinary nature, the search for basic principles that underlie all complex systems is a major focus of complex systems research. The following principles are derived from this research (Beabout, 2012):

1. Complex systems are non-linear, open, and far from equilibrium.
2. Complex system behavior involves adaptation to the environment, based on experience.
3. Complex system behavior is a function of internal models or schemas that are the result of perceived regularities in experience.
4. Emergent global complex system behavior involves the aggregate behavior of agents
5. Internal models and schemas are actively constructed, self-organized, and emergent.
6. Internal models and schemas are a function of both agent interaction and existing internal models and schemas.

Each of these principles has been discussed and exemplified in the preceding section. As general tenets of complexity, these principles may be applied to a wide array of complex systems. One such system involves human learning. Each of these principles may be applied to the process of learning, in general, and the theory of constructivism, specifically.

Complex Constructivism

Complexity and constructivism are two theories that provide functional and robust metaphors. Complexity provides a metaphor for myriad phenomena, while constructivism provides a metaphor for learning. In the synthesis of these two powerful metaphors lies a new metaphor - complex constructivism. According to Lakoff and Johnson (1995), “New metaphors have the power to create a new reality” (p. 145).

The reality of complex constructivism is one in which the non-linear, adaptive, and constructive nature of learning is embraced. Complex constructivism views learning as the active construction and adaptation of one’s internal models of reality based on the interaction between oneself and one’s environment (including other persons), such that the functioning of one’s internal models exceeds the sum of the models’ components. This definition leads to six general principles of learning based on complex-constructivist ideals:

- learning involves an individual’s adaptation to the environment;
- learning involves the active construction of knowledge by the individual;
- learning involves the self-organization of knowledge and experience into internal models;
- learning involves the emergence of internal models as a natural consequence of an individual’s on-going experience;
- learning is a function of both individual interaction and existing internal models; and
- learning occurs within agent hierarchies and selection pressures that includes individuals, family, friends, and local and global culture.

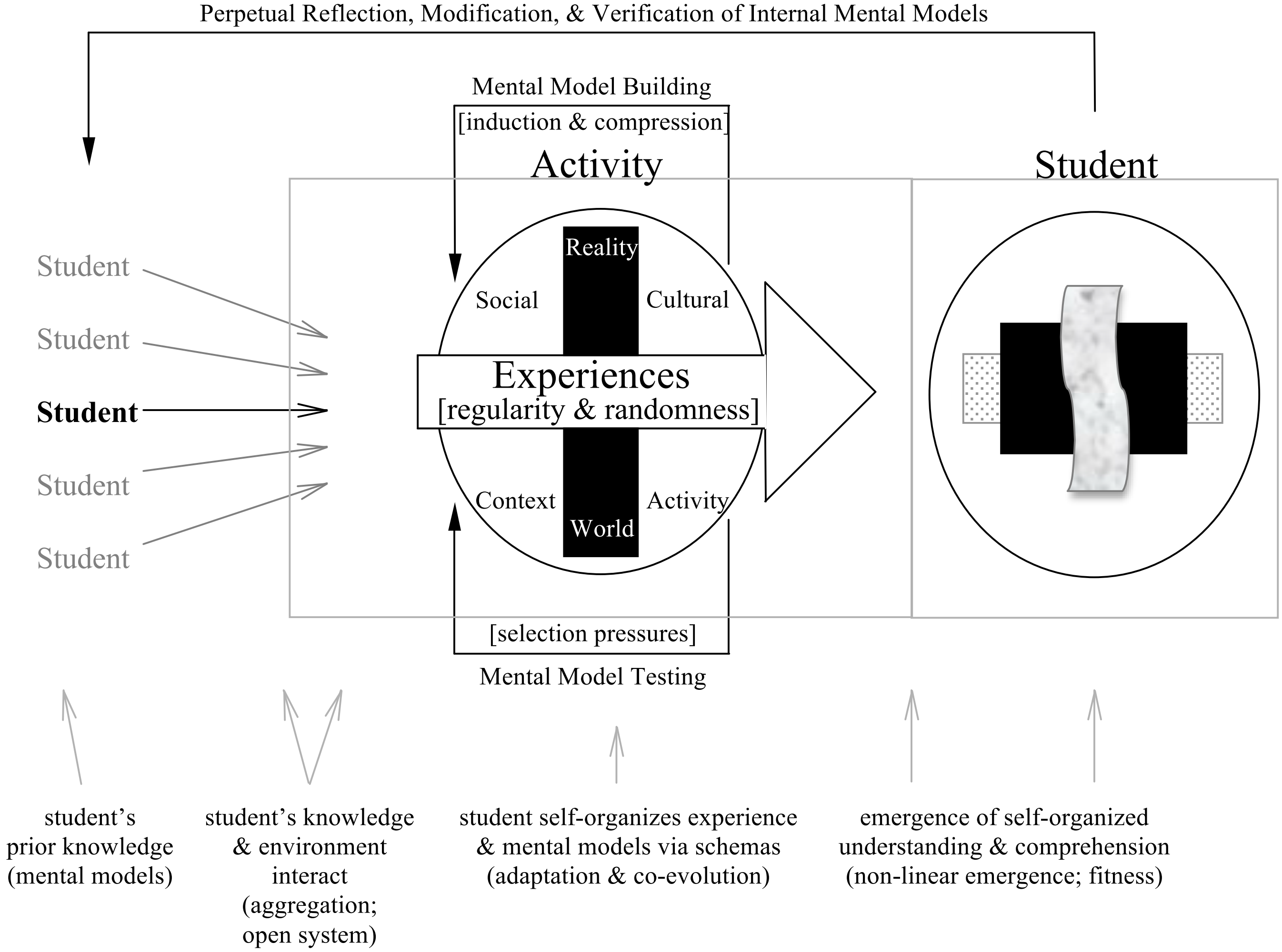
These general principles emerge from the synthesis of complexity theory and constructivist theory to provide links to a new perspective on learning, memory and cognition. These principles also provide a foundation upon which to build new ideas relating complexity and constructivism. Figure 7 is a graphical model of the relationship between these principles, based on the earlier models of constructivism (Figure 4) and complexity theory (Figure 5).

The complex-constructivist model in Figure 7 represents the self-organized and adaptive nature of learning. Students enter an experience with existing internal (mental) models, or schemas, that allow the student to predict how the experience may transpire, to prescribe desired behaviors based on the predictions, and to describe the experience as it occurs. However, students with limited existing internal models related to the current experience will have only a limited ability to predict, prescribe, and describe, while students with more well developed internal models will be able to predict, prescribe, and describe more effectively.

These students’ internal models are affected by not only the experience, but also interactions with other students and their internal models. As the students are engaged in the experience, and potentially interacting with other students, the students are determining which aspects of the experience are familiar, and which aspects of the experience are novel. The recognition of familiar experiences indicates the existence of internal models relative to the experience, while a lack of familiarity indicates the non-existence of a related internal model. An existing internal model represents the student’s prior identification and compression of regularities within this type of experience.

The process of recognizing and compressing regularities is paramount to students constructing internal models. Regularity is knowledge. As students encounter experiences, they begin to actively look for regularities and compress these regularities into an abbreviated form (schemas), that is, the students begin to actively construct knowledge from within the vast array of stimuli in the experience, based on existing internal models. This process of active regularity extraction, or active knowledge construction, is fundamental to making meaning from the experience. The student’s make an experience meaningful by relating the experience to the regularities existing

Figure 7
Complex Constructivism



within their internal models (i.e., prior knowledge). If an experience contains many regularities that already exist within the student's internal models then the experience is highly meaningful.

As students gain experience and actively identify regularities, these regularities will self-organize to form internal models. That is, the way that a student organizes their knowledge is a function of the student, not the experience. The experience may indirectly influence or intimate as to how this knowledge might be organized, but the actual organization is dependent upon the student and their existing internal models. In addition, as related knowledge coalesces, or perceived regularities cluster, a more cohesive entity begins to emerge—an internal model. These internal models provide both a framework for knowledge and a formulation of the integration of the knowledge. Thus, internal models emerge from the abstraction of regularity and knowledge, and as such, are personal constructions of the student.

Finally, these internal models are continually re-engaged in various experiences to provide for adaptation. If the nature of familiar experiences changes, then new regularities or knowledge will be abstracted, and old internal models will be modified or new internal models will be constructed.

The preceding description has been fairly linear due to the constraints of written language; however, it should be noted and emphasized that this process of learning and adaptation is dynamic, cyclical, and very non-linear.

Complex Constructivism Principles

Complex constructivism principles are based on the shared fundamental tenets of both complexity theory and constructivism theory. These principles provide a solid foundation for understanding the nature of learning in a complicated, dynamic, and culturally relevant world. Holland (1998) provided an excellent introduction:

> Despite the perpetual novelty of the world, we contrive to turn experience into models of that world. We *learn* how to behave, and we anticipate the future, using the models to guide us in activities both common and uncommon. Somehow, through learning, these models emerge from the torrent of sensations that impinge upon us at every moment. (p. 53)

1. Learning involves student adaptation to the environment. The concept that an organism alters its behavior to more effectively interact within its environment is common to both a constructivist and complexity perspective. For constructivists, this adaptation involves the construction of new mental structures, and the modification of existing mental structures, to facilitate students in interacting meaningfully and effectively within their sociocultural and physical environments. Eisenhart and Broko (1991) stated the constructivist perspective well: "Learning occurs as [students] make sense of instructional events by using their existing cognitive structures to interpret environmental stimuli. It also occurs as they modify and elaborate their knowledge structures through a process of adaptation to the environment" (p. 142). This concept of constructing and modifying internal models in order to adapt to an environment is mirrored in complexity theory. Martin (1999), in delineating the essential characteristics of a complex system, stated, "As a rule, these systems are *adaptive*; changes in their internal states occur in response to the environment" (p. 263). Indeed, Waldrop (1992) bridged the gap: "In fact, you can think of internal models as the building blocks of behavior. And like any other building blocks, they can be tested, refined, and rearranged as the system gains experience" (p. 146).

2. Learning involves the active construction of knowledge by the student. There are many types of constructivism; however, their unifying theoretical tenet is the belief in an active learner, a learner that actively constructs knowledge from experience. This construction process is responsible for students "internalizing" their culture and making sense of their environment. This act of construction applies equally well from comprehending basic math facts to comprehending cultural mores. Comprehending and making sense of an environment, as a complex agent, involves the active search for regularities. These regularities reflect knowledge of the environment and allow agents to successfully adapt. Therefore, from a complex constructivist perspective, students construct internal mental models by actively searching for regularities in their experience.

3. Learning involves the self-organization of knowledge and experience into internal models. Constructivism and complexity both emphasize that the organization of students' or agents' internal models is a process that is carried out exclusively by the student or agent. That is, the organization of a student's or agent's knowledge or internal model is not imposed on the student or agent by either an internal or external source. This does not negate the influence of society and the environment; rather, society and the environment have an indirect influence on self-organization, as an impetus for adaptation. Therefore, self-organization accounts for the individualistic or subjective nature of knowledge and "the view that learning is both a process of self-organization and a process of enculturation that occurs while participating in cultural practices, frequently while interacting with other" (Cobb, 1989, p. 41).

4. Learning involves the emergence of internal models as a natural consequence of a student's experience. The complex constructivist perspective posits the idea that internal models are not "actively constructed," but rather, internal models are "naturally emerging." This statement is not as antithetical to a constructivist view as it may first seem. Students' active construction involves the active search for regularities in their experience and these regularities represent knowledge. However, the internal models that provide the relational organization of this knowledge emerge as a natural consequence of knowledge acquisition. Thus, the knowledge is actively constructed while the organization is naturally emerging. Furthermore, these naturally emerging internal models provide the non-linear foundation for the concept that the whole, the internal models, is greater than the sum of the parts, the knowledge. "The ascending levels of the hierarchy of complexity demonstrate emergent properties at teach level which appear to be non-predictable from the properties of the component parts" (Cowan, 1994).

5. Learning is a function of both student interaction and existing internal models. Within constructivism, this complex constructivist principle combines the social interactionist views of the sociocultural constructivists with the personal constructivist views of the radical constructivists. This dualism also exists, although to a lesser extent, within complexity between the individual agent view of Gell-Mann (1994, 1995) and the aggregate agent view of Holland (1995, 1998). Cobb and Yackel (1996) provided support for this principle of combining the individual and the social by eschewing this duality and proposing an "emergent perspective" to constructivism that integrates these two views. Yackel (1995) explained this relationship:

> The characterization of learning as an individual constructive activity is, therefore, relativized because these constructions are seen to occur as students participate in and contribute to the practices of the local community. . . . The link between collective and individual process in this approach is, therefore, indirect because participation enables and constrains learning but does not determine it. (p. 185)

Complex constructivism provides a new perspective on learning, a perspective that emphasizes both the active, self-organizing construction of knowledge, and the adaptive nature of those constructions. The complex constructivism perspective combines and addresses the common concerns of constructivism—

> A psychology that decomposes . . . thinking into its elements in an attempt to explain its characteristics will search in vain for the unity that is characteristic of the whole. These characteristics are inherent in the phenomenon only as a unified whole. Therefore, when the whole is analyzed into its elements, these characteristics evaporate. (Vygotsky, 1987, p. 45)

—and complexity, "Modeling the emergent characteristics of the mind presents probably the most difficult task for creating links between the hardware and software of human biology and the achievements of human consciousness" (Singer, 1995, p. 5).

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