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Principles of Self-Organization: Learning as Participation in Autocatakinetic Systems

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Modern science has been built on a Cartesian or Newtonian (mechanical) world view giving rise to an artifactual view of mind and suggesting that particles (learners) are continuously working to destroy order (are recalcitrant), which can only be maintained by an external artificer (the teacher). At the core of the Cartesian worldview is the absolute separation of mind and matter. Beginning with the separation of mind and body, Cartesianism is grounded in a set of dualisms that separate individual from environment and leads to the belief that knowledge refers to a self-sufficient immaterial substance that can be understood independently from the individual, environ-

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ment, and context in which it is situated. In contrast, we make the argument for an alternative set of assumptions predicated on a *relational ontology* and grounded in recent developments in the understanding of self-organizing systems. In our view, knowing, meaning, and cognition are actualized through the dynamic between learner (self) and environment (nonself), and that which is neither the learner nor the environment. We further argue that the ecologized, or self-organization, model (relational ontology) establishes that (under the appropriate conditions) the particles (learners), in effect, "want" to or strive opportunistically to order themselves once the intention has been properly initialized. From this perspective, instruction involves establishing the appropriate field conditions or connecting the learner into a system (a set of relations) through participation (e.g., as part of a community of practice) in the service of an intention. The type of learning that we are advocating cannot be handed to the learner wholecloth but develops itself through dynamic activity (participation) as part of a system as a whole. Central to this line of reasoning is the assertion not only that learner practices and meaningful relations that arise due to their functional significance as part of a dynamic system are fundamentally different from teacher- or textbook-owned descriptions of practices and meanings, but that they are in this way far richer, more meaningful, and more functional. Context and participation, to put it directly, not only matter but in a deep and fundamental way are everything.

> In parts of West Africa they use an ingenious little device called a Monkey Trap. The trap itself is a very simple design, in which rice is placed in the center of a box that has a tube running from the outside to the center. When the monkey places his hand in the box, which is just wide enough for his unclenched fist to pass through, he grasps a handful of rice and while holding the rice he cannot remove his arm. In spite of the fact that the monkey could remove his arm if only he would let go and unclench his fist, the trap is surprisingly effective. The trap's effectiveness can be credited to the monkey's thoughts in relation to the affordances of the trap, not solely the mechanism of the trap or the monkey's thoughts. (Yoruba Oral Tradition)

The assumptions we hold about human nature and what it means to know and learn influence the selection of phenomena considered relevant for educational research, the types of research questions we ask, and ultimately, how we interpret results (Barton, 1994; Ennis, 1992; Kuhn, 1970). These assumptions are potentially beneficial in that they provide a lens for focusing our study of the world, but when they are held too tightly can become a "trap" that prevents us from adopting models and theories that are consistent with real-world phenomena. For example, education may be trapped in the assumption that learning is a unique type of practice caused by some informed other and only occurs within the controlled environment of schools. In contrast, others are adopting a different perspective—one that acknowledges learning and doing as a part of all activity, naturally arising through participation as part of the lived-in world (Barab & Duffy, in press; Engestrom, 1993; Lave, 1988, 1993, 1997; Lave & Wenger, 1991; Kirshner & Whitson, 1997; Rogoff & Lave, 1984; Saxe, 1992; Suchman, 1987; Swenson, 1989b).

Rooted in Cartesian dualism and Newtonian mechanics, learning approaches predicated on objectivism (or reductive materialism) and constructivism have at their basis an incommensurability between knower and known. According to Descartes (1637/1978), on whose metaphysical assumption the physics of Newton was built, the world was said to consist of an active, striving, end-directed psychological part ("perceiving mind"), and a "dead," physical part ("matter"). It was the function of the striving, immaterial mind to impose order on the physical part made up of inherently qualityless particles incapable of ordering themselves. This view received apparent support from the later thermodynamics of Boltzmann (1886/1974), which held that universal law (the second law of thermodynamics or the entropy law) was constantly working to destroy order. From this, the world came to be viewed as comprised of two incommensurable "rivers," the river of physics flowing down to disorder and the river comprising the epistemic dimension of the world (psychology, biology, and culture) flowing up to increasingly higher states of order. According to this paradigm, the educator is given an impossible role, that of fixing the breach, bridging the incommensurability of knower and known, or reconciling the otherwise incommensurable rivers.

Restating this important point slightly differently for emphasis, with the reduction of the world to the collision of mechanical particles or to an extremely impoverished notion of causality, or cause and effect (what Aristotle would have called "efficient cause"), all end-directed behavior (telos) had to be illegitimately smuggled in or imposed extraphysically from outside. Cartesian-based theories, in different terms, require illegitimate teleology to get them working, for example, extra-physical or immaterial ideas, thoughts, or rules as in the "rule-governed" models that typically characterize artifactual views. For example, the predominant view in cognitive science is to liken the mind to a computer, depicting the mind as a computational machine that arranges cognitive symbols residing in the brain (Gardner, 1985; Simon, 1995). However, using artifacts as models for nonartifactual systems is a "category error," producing "nice" models that are not only inconsistent with everyday experiences (Swenson, 1997b), but collapse a priori on fundamental empirical and logical grounds. Beyond the violation of, as far as anyone knows, inviolable conservation laws (perhaps the deepest understanding of the problem of dualist interaction), as Putnam (1980; Swenson, in press-a), for example, has shown, syntactical or rule-based systems cannot, for simple formal reasons alone, be the source of intentionality or semantic content. This problem lies at the heart of what others have referred to as the *problem of intentionality* or the *symbol-grounding problem*, a problem that is even readily admitted by leading proponents of the computational or algorithmic view (e.g., Fodor's [1980] "methodological solipsism"). Educational practices emphasizing the teaching of decontextualized, and what amounts to semantically void generative rules, must fail at their cores for precisely the same reasons.

Implications of the artifactual view for education are that the "order" to be created is imposed on the learner who is expected rotely to memorize "facts," which, purportedly, can later be matched up in a meaningful way with some real-world phenomena. Constructivism, a species of closed-circle theory and thus a direct descendant of Cartesian postulates only now regressed with compounded problems to the sociological level (see Swenson, in press, for a fuller discussion of the derivation and implications of closed-circle theory), holds that reality is the creation of individual learners. Although such an approach may be intuitively appealing, it also separates individual (the active constructor) and environment (or lack thereof), setting up a closed circle of "meaning" where no principled basis or explanation is offered for how the learner can know about an external world or another individual's view of it (Goerner, 1994; Reed, 1991; Swenson, 1991, 1997a).

In contrast, in our view, the world offers information in the form of material content, patterns, and invariant properties, all of which provide the basis for the actualization of meaningful relations. Knowing about, cognitive activity, and meaning do not exist as isolated components of individuals or of the environment; rather, they emerge as sets of relations forming through dynamic interactions. More specifically, meaningful relations become actualized through the dynamic between learner (self) and environment (nonself) and that which is neither the learner nor the environment. Swenson (1999) has made the point clearly:

> if intentionality is minimally defined as a kind of dynamics distinguished through the production and maintenance of persistent or invariant self–other relations rather than a property of decontextualized mental states or representations (or algorithms or symbols) ... the place to look for meaningful content (is) not in the normal physical descriptors of individual particles, but instead in the variables of the flow itself. (p. 21)

More generally, we argue that cognition (or cognitive activity) and knowledge (or knowing about) all exist in the "flow itself" (Coulter, 1989).

A view that embeds meaning in the dynamics of the world (which includes the interacting self, nonself, and that which is neither the self nor the nonself) is in contrast to the Cartesian paradigm, which does not bring the learner and environment into relation with the world but instead irrevocably separates all these components. Cartesian theories, as we have argued previously, fail by definition to form the basis for an informed and effective theory of instruction and, in fact, we would assert more strongly, mitigate against it. The particles (in this case, the learners) in the Cartesian or Boltzmannian view (and "didactic" models) are assumed to be recalcitrant to ordering or learning. As such, it is the responsibility of the educator to order disembodied information and present it in a systematic fashion (Gagne, Briggs, & Wager, 1993). Many educational philosophers have argued that our educational system, characterized by a didactic pedagogical base intended to most efficiently cause the learner to master specific objectives, is an ineffective, if not dehumanizing, model, one that has the effect of removing the learner from the very context in which meaning resides (Dewey, 1963; Walkerdine, 1997; Whitehead, 1929), and our brief previous discussion shows in a deeper way just why this is the case. The anthropologist Jean Lave (1991) stated that schools "decompose" activity to the point that learning is meaningless, according "knowledgeable skill a reified existence, turning it into something to be 'acquired' and its transmission into an institutional motive" (p. 79). The belief that experience can be decomposed, departmentalized, and then taught as a self-sufficient substance has its roots in a mechanistic–dualistic model, consistent with an artifactual view of mind, and stands in sharp contrast to a self-organizing model of human development (Swenson, 1997a, 1997b).

An ecological model, or a model based on a relational ontology, grounded in current principles of self-organizing or spontaneously ordered systems, contextualizes (ecologizes) the learning situation and not only better captures the world as it is, but, we suggest, also dramatically potentiates the learner–facilitator interaction. Instead of advocating for the systematic and didactic presentation of abstract content, a self-organizing model points to the importance of fully contextualized experience in which there is no artificial separation between the act of learning, of participation, and the context in which it arises. Said another way, it advocates for the necessity of experience in which the learner/participant interacts with the real world to address real dilemmas. Participatory models of learning in which learners are actively engaged as part of a dynamic system are consistent with many of the exciting projects being advanced by educators, for example, Scardamalia and Bereiter's (1993) knowledge-building communities, Brown and Campione's (1990) communities of learners, the Cognition and Technology Group at Vanderbilt's ([CTGV], 1993; Barron et al., 1995) SMART project, Koschmann, Kelson, Feltovich, and Barrows' (1996) problem-based learning, and Barab and Landa's (1997) Integrated Units, to name a few. In all of these projects, learning is not viewed as an isolated activity that is externally arranged and context independent; instead, learning (participation) is (re)contextualized as a participatory process involving contextualized practice and meaning, as part of an ecological system. However, we also argue that the activity and designing that takes place within schools often assumes the values of the school context—complex problems are solved to get a good grade and assignments are completed for the purpose of satisfying a teacher or parent, not for the purpose of accessing deeper levels of meaning. The more remote school experiences are from the breadth of relevant contexts, the less likely it will be that the learner will find meaning.

From an ecological perspective, instruction involves mediating key elements of a larger context so as to facilitate the merging of learner and environment into a single system. As learners work toward functional goals, the facilitator guides their practice to support the emergence of meaningful relations. Learner ownership of functional practices and meanings need not, and we would argue, cannot, be externally arranged by the teacher for the student; rather it flows as part of the self-organizing dynamics that are uniquely emergent when the individual becomes a member/participant in an ecosystem or context for a task. As such, the facilitator must enter, support, and become part of the learner's and the community's ecosystem, where he or she has the responsibility to provide constraints (scaffolding) as initial conditions that work to promote naturally emerging dynamics (Shaw, Effken, Fajen, Garrett, & Morris, 1997; Shaw, Kadar, Sim, & Repperger, 1992). However, over time, as the learner becomes "coupled" with an intention and resonates with the boundary conditions, it is the responsibility of the facilitator to gracefully remove himself or herself from the interaction, allowing the learner to establish direct effectivity–affordance relations with the community.[1] It is through the production of intentions whose satisfaction gives rise to particular effectivity–affordance couplings that the learning/enculturation process occurs (Barab, 1999). It is central to the ecological model being advanced that the individual, the task, the intention, practices, meanings, and environmental particulars exist as part of an interrelated system—not as isolated components. As long as educators continue to separate content from context, information from application, learning from participation, knowledge from experience, they will sever the essential connection that facilitates the learner in developing meaningful relations in the world.

Having outlined the problem, the goal of this article is to provide a general description of and beginning vocabulary for the philosophical shift in viewpoint that comes with a nonlinear systems approach focusing on self-organization and the implications of this shift for contextualizing knowing about, learning, and instruction. From the outset, however, we acknowledge that our goal is not to advance a "prescriptive" instructional theory (Reigeluth, 1999), but to illuminate (and bring to the educational discourse) a language and "principled" account through which new theories and interventions can be developed. A principled account in this case refers to one that follows from, and is grounded within, natural law.

The remainder of the article begins with an ecological approach as an alternative to the more commonly held dualistic theories. Consistent with this ecological approach, knowing about is described in terms of the merger of learner and context that, through participation, allows meaningful relations to emerge for the individual in context. This is followed by a discussion of self-organizing systems, highlighting the principles that we believe to have implications for learning and instruction, including autocatakinetic systems, macrodeterminancy, formal cause, and intentional dynamics. More specifically, this discussion advances the theory of self-organizing systems, dissolving the problem of incommensurability between the two "rivers," and thereby between knower and known or self and other, and shows why spontaneous order rather than being anomalous with respect to natural law is an expected consequence of it. Communities of practice and their constituent members are then defined as nested self-organizing systems, illuminating the codeterminancy and the function of a community for the individual and the individual for the community, and the community in its larger context. The critical role of intention is then grounded in the dynamics of autocatakinetic systems, providing a means for coupling individual and learning environment.

[1] Further, we assert, although a deeper discussion of this point is beyond the scope of this article, that oppositional or noncompliant behavior with respect to certain communities of practice or cultural systems is unavoidably functional behavior not only for individual development but for cultural development, learning, or functional behavior writ large.

ESTABLISHING THE DUALISMS

Commonly held theories polarize learner and context, postulating the distinct unidirectional and linear flow of cause onto effect (Pepper, 1942/1974) or, in the case of education, from teacher to student. Western science, relying almost exclusively on dualistic (Decartes) and mechanistic (Newton) models for inspiration, has been associated with this mechanistic picture of the world. The world (from this perspective) would be considered to be governed by linear, mechanical, cause-and-effect relations (efficient cause), with all things being predictable and controllable. The direction of causal efficacy is from the causal agent to the caused, from the action of the actor to its results on the acted-upon.

The outcome of these mechanistic (and organismic) biases is that psychology is divided into a set of post-Cartesian dualisms: stimulus–response versus cognitive, reactive versus motivated, innate versus learned, objective versus constructivist, sensation versus perception—all of which stem from the overriding dualism separating individual and environment (Swenson & Turvey, 1991; Turvey & Shaw, 1995). This polarization of learner from environment creates problems that in effect isolate the self from its world, the body from its mind, the content from its context, and the parts from the whole. The history of such dualistic thinking reveals its inadequacies as a way of explaining thought and knowledge in that it sets up an incommensurability between knower and known, with one language to describe that which is known and another to describe the individual doing the knowing (Lombardo, 1987). When Descartes postulated a mind apart from its body, he was then forced to find a mechanism to put them back into communication. When Simon (1995; Newell & Simon, 1972; Vera & Simon, 1993) and his followers postulated algorithms that controlled information processing, they were faced with an infinite regress of meta-operations, of homunculi in the brain (Calvin, 1996;

Edelman, 1992; Posner, 1978). When Skinner proposed a body without a mind, he was faced with the paradox of being an agent who was voicing an opinion about agents who could hold no opinions.

Clearly, dualistic lines of thought dominate the field of cognitive psychology. According to the mind-as-computer paradigm, knowledge (as opposed to knowing about) is an independent substance that can be represented as a set of symbols arranged in a syntactically meaningful order (Newell & Simon, 1972). Further, it is considered to be disembodied and can, therefore, be investigated without reference to the context in which it is situated (Kirsch, 1991). In recent years, the computational view has come under increasing attack for both formal reasons as well as obvious empirical ones (Johnson, 1987; Juarrero, in press; Lakoff, 1987; Swenson, 1999; Thelen, 1995; Thelen & Smith, 1994; van Gelder & Port, 1995). The fatal problem with dualistic theories predicated on rule-based systems has been discussed previously in this article. From an educational standpoint, the dualism that has proven most pervasive is that which attempts to separate content from context.

Content–Context Dualism

A common belief held by many educators and policymakers extends this dualistic thinking to suggest that knowledge can be described in terms of specific objectives and imparted without recourse to the communities of practice who value it (such as scientists, mathematicians, and journalists) or the situations in which it is valued (see Anderson, Reder, & Simon, 1996). Learning activities become organized around pedagogically structured content with fact acquisition rather than meaningful participation as the goal (Lave & Wenger, 1991). Integral to this line of reasoning is an objectivist–dualist epistemology, in which it is assumed that facts, concepts, principles, and skills are independent from those situations in which they are learned and used. These assumptions have led to didactic pedagogical approaches in which the goal of instruction is for the all-knowing teacher to transfer abstract and potentially generalizable content to the passive learner. It is simply assumed, and central to the representational/symbolic view of mind, that learners can and will apply these abstracted facts, concepts, principles, and skills when the relevant situations present themselves.

It is generally believed that generalizable learning must occur *out of context if* it is to transfer to multiple situations, and that only out of context learning can lead to abstraction, generalization, transferable knowledge, and cognitive efficacy in future life situations. Lave (1997) commented that it appears that the "academic and educational establishments are caught in a serious dilemma concerning the role of distance from experience in strengthening and at the same time weakening learning" (Lave, 1997, p. 28). Further, it is the teachers in this traditional pedagogical

framework who take responsibility and ownership for the learning process. They are held accountable for motivating learners, who are considered the objects of change.

Learning importance is assessed in terms of aiding the student in achieving higher scores or in terms of the learner's ability to "buy in" to the significance attributed to a particular practice or meaning by the teacher or textbook—not in terms of its meaningful application with respect to real-world phenomena for which it has functional significance. As such, exchange values[2] replace the value of participation (Lave & Wenger, 1991). Clearly, education has inherited a dualist hierarchy (leading to a separation of content from context), with the didactic presentation of abstracted material constituting the core principle of the educational system. Kirshner and Whitson (1997) stated that

> The central philosophical assumptions against which situated cognition theories struggle is the functionalist belief in mind–body dualism (Lave, 1988). Viewing the world of a person's ideas, beliefs, and (intellectual) knowledge as autonomous—essentially disconnected from their bodily (i.e., lived) experience, and hence from their sociocultural context—provides broadly for a devaluing of lived experience in favor of "higher" (abstracted) contemplative activity. Because this dualist hierarchy denies the means to abstraction (through experience), it is highly corrosive to educational enterprises. (p. 4)

It is in an attempt to shed the shackles of our dualist roots and to couple individual and environment and content and context that we enter into discussions of ecological psychology and situativity theories.

ADOPTING AN ECOLOGICAL APPROACH

In contrast to organism–environment dualism, Plato's most renowned student, Aristotle, posited that the knower and the known are united in a functional interdependence. Although Aristotle distinguished the knowing mind from that which is known, he also stated that in reality the two are inseparable. Based on this Aristotelian heritage, a line of thought emerged that challenged the analytic, static, and segmented thought of absolute dualism. This was particularly evident in the natural sciences, where "the structures and capacities of animals were described relative to their ways of life within an environment; in turn, the environment was described

[2] Exchange value in this context refers to *value* whose importance is not attributed to that which is learned directly; rather it is attributed to those outcomes for which learning the information can be exchanged. Tests constitute one of the most common means of establishing an exchange value for knowledge, in that learning to display knowledge for evaluation can be exchanged for high grades on tests (Lave & Wenger, 1991).

relative to the ways of life of animals" (Lombardo, 1987, p. 5). In psychology, the functionalists were less concerned with "what is mind?" than with "what is mind good for?" The central focus of functionalists (C. S. Peirce, William James, and John Dewey) was on what adaptive purposes justify the existence of mind; this work served as a precursor to the work of James J. Gibson (Turvey & Shaw, 1995).

Gibson's (1986) ecological approach avoided dualism by *not* describing the objects of the world as propertyless, simply defined by their extension, and by *not* describing meaning as residing solely in the head. Gibson's (1986) ecological view took individuals to function within an *ecosystem* and their perceptions as only describable within the context of that system; perception (or what Gibson referred to as "perception about") was seen as the act by which an animal maintains epistemic contact with the environment. Gibson introduced the notion of *affordance*, a term that simultaneously captures and couples objects and events of the world to the individual's behavior (Reed & Jones, 1982). An affordance is a combination of invariant properties in the environment, taken with reference to an organism, that specifies an opportunity for action (Gibson, 1977; Turvey, 1992). Gibson postulated these affordances in the ontology, not the construction, of the perceiver. Consistent with Gibson's (1986) ecological notion of perception–action, affordances are properties of the environment whose actualization requires an individual with reciprocal *effectivities*; an effectivity is the dynamic actualization of an ability by the individual taken with respect to a particular opportunity for action (Shaw & Turvey, 1981). However, affordances do not *cause* behavior (including perception and cognition) in the efficient causal or ballistic sense; rather, affordances are *opportunities* for action.

For an affordance to be the successful goal of an action, there must be an affordance–effectivity fit of organism and environment. The environment, functionally defined as an *econiche*, is all those affordances (opportunities for actions) for a given class of organisms who have the mutually compatible effectivities. Effectivities, now functionally defined, are those behaviors an organism can, in fact, produce so as to realize the available affordance goals. Perception about is the act of detecting information about the environment. But perceptual information is graded by its relative invariance under different circumstances and in relation to the organism's effectivities. Although properties of the environment that are not obvious or relevant may be perceived, their salience or attensity (the probability of their being attended to) is of a lower grade (Shaw, Flascher, & Mace, 1994). This notion of perceptual salience (attensity) has clear and important implications for the design of circumstances under which individuals might learn or be instructed, suggesting that the goals and intentions of the learner are primary in actualizing meaningful relations.

Ecological psychologists have collected evidence to support the contention that the environment is punctuated by qualitative regions of functional significance for an agent with the requisite reciprocal effectivities. These studies have examined environmental affordances with respect to crawlable surfaces (Gibson et al., 1987), steppable heights (Pufall & Dunbar, 1992; Warren, 1984), sittable heights (Mark, Balliett, Craver, Douglas, & Fox, 1990), passable apertures (Warren & Wang, 1987), and time to contact (Kim, Turvey, & Carello, 1993). Implications of this research are that it is not necessary to posit inferences to symbolic calculations on the part of the observer; what is needed is a better understanding of environmental affordances and how the user becomes apprised of these possibilities for action—more physics to accompany our psychology.

Gibson did not deny the existence of physical objects or individual differences in terms of perceptions of the world; rather, he introduced a language (ecologese) and psychology that functionally coupled them. Postulating this coupling, and the importance of grounding it within the context in which the knowing occurs, Gibson avoided knower–known dualism. In contrast to knowledge–process dualism, knowledge and processes merge into a single dynamic in which knowing about evolves in relation to the boundary conditions set by the current effectivity process assembled by the learner in relation to what the situation affords (Shaw & Turvey, 1981). Through experience with various environments and their nested affordances, the individual becomes apprised of what changes and what remains the same (Gibson & Gibson, 1955). In this way, ecological psychologists are able to account for individual perceptions of change (variance) and permanence (invariance) without the postulation of further mental processes (see Gibson, 1977, for extended discussion of this theory). Subsequent interactions are not dictated by individual or environment; they emerge out of the dynamics of the interaction itself—an affordance–effectivity "fit" (Suchman, 1987). On this view, meaning is not solely in the environment or solely in the individual but in the flow (the relation) between them. An effectivity in this language is the situated dynamics.

SITUATIVITY THEORIES: COUPLING CONTENT, PRACTICE, AND CONTEXT

Although Gibson's writings were primarily concerned with perception, his ecological coupling of individual–environment and meaning–context are consistent with current views of cognition as situated (Brown, Collins, & Duguid, 1989; Greeno, 1998; Kirshner & Whitson, 1997, 1998; Lave, 1993; Lave & Wenger, 1991; Young, 1993). The field of cognitive science is moving from claustrophilic theories that emphasize individual thinkers and their isolated minds to situativity theories that emphasize the reciprocal character of the individual and his or her social and material context (Barab & Duffy, in press). In Brown et al.'s (1989) seminal piece on situativity theories and the culture of learning, they suggested that learning is always situated and progressively developed through activity. They further suggested that the notion that concepts are *self-contained entities* should be abandoned; instead, they should be conceived of as *tools* that can be fully understood only within use. It is their contention that learning involves more than acquiring information but actually involves building an "increasingly rich implicit understanding of the world in which they [learners] use the tools and of the tools themselves" (Brown et al., 1989, p. 33). This understanding is framed by those situations in which learning/applying occurs.

Cognition is explained in terms of the relation between learners and the properties of specific environments (Young, 1993). Situativity theories assert that thinking involves an interaction among individuals and physical and social situations (Bredo, 1994; Clancey, 1993; Greeno, 1997, 1998; Greeno & Moore, 1993; Lave, 1997; Lave & Wenger, 1991; Resnick, 1989; Roschelle & Clancey, 1992; Young, Barab, & Garrett, in press). Knowledge is described as fundamentally situated (knowing about), emerging in context and spread across the relations among activity, content, and context. It becomes impossible to separate the learner, the material to be learned, and the context in which learning occurs. From this perspective, knowing about is no longer conceived of as a static structure residing in the individual's head; instead, knowing about refers to an activity that is distributed across the knower, that which is known, the environment in which knowing occurs, and the activity in which the learner is participating when learning/knowing occurs—a dynamic unfolding of the perception–action cycle. Knowing about is deeply embedded in active participation within the social/material world. Learning is therefore context dependent, and there is a relation between knowing about the world and the world that is being known. This dynamic grounding of situativity theories makes it difficult to argue for "the separation of cognition and the social world, the form and content of learning, or of learning and its 'applications'" (Lave, 1997, p. 32). Instead, like ecological psychology, situativity theory is an attempt at unification of the world, the individual, and the relations among these reciprocal components.

Central to this perspective is the primacy of practice, where participation couples knower and material/social context into a reciprocal relation, giving the knower membership in a dynamically constituting community of practice (Lave, 1997). This line of thinking is apparent in Sfard's (1998) discussion of the *participation metaphor* (PM), a notion that has become central to situativity theories:

> Just as different organs combine to form a living body, so do learners contribute to the existence and functioning of a community of practitioners. ... PM makes salient the dialectic nature of the learning interaction: The whole and the parts affect and inform each other. On one hand, the very existence of the whole is fully dependent on the parts. On the other hand, ... the PM implies that the identity of an individual, like an identity of a living organ, is a function of his or her being (or becoming) a part of a greater entity. Thus, talk about the "stand-alone learner" and "decontextualized learning" becomes as pointless as the attempts to define lungs or muscles without a reference to the living body within which they both exist and function. (Sfard, 1998, p. 6)

As participation couples knower and known, or individual and community, it takes on and imbues meaning, within context, through the function it serves. As the goal is met, the function served flows back on the action, imbuing it with contextualized meaning.

This notion places meaning within context-embedded experience, where practice takes place in the context of meaningful relations. *Understanding-in-practice*, a term coined by Lave (1997), "can be neither fully internalized as knowledge structures nor fully externalized as instrumental artifacts or overarching activity structures ... [Rather] understanding and experience are in constant interaction—indeed, are mutually constitutive" (Lave & Wenger, 1991, pp. 51–52). This is consistent with Wenger's (1998) description of meanings as arising in the interaction. The particular meaningful relations that emerge are, in a very real sense, dependent on the self-context relation in which particular constraints make certain meanings more functional, indeed more probable, than others (Bereiter, 1994; Dewey, 1925/1981); that is, context places boundary conditions on the particular meanings that emerge. One implication is that "wisdom can't (simply) be told" (Brandsford, Franks, Vye, & Sherwood, 1989).

The previous discussion suggests a reformulation of what it means to know and learn, from a dualist representational theory separating knowing from that which is known to one that situates practice and meaning within context and suggests reciprocal, as opposed to dualistic, relations among learner, practice, meaning, and context. Situativity theories suggest that interactions within the world are viewed not only as revealing meanings about the world but also producing identities in the world. In other words, "developing an identity as a member of a community and becoming knowledgeably skillful are part of the same process, with the former motivating, shaping, and giving meaning to the latter, which it subsumes" (Lave, 1991, p. 65). As such, individuals are fundamentally constituted in their relations with the world and the nested communities of practice (Barab & Duffy, in press; Lemke, 1997; Walkerdine, 1997). Reciprocally, communities of practice are fundamentally constituted in their relations both with individuals and the larger context in which they are embedded.

A full account of cognitive activity (as opposed to static cognition), knowing about (as opposed to static knowledge), and meaningful relations (as opposed to the collection of given symbols or data points) must include an account of ongoing change, the development (i.e., emergence) of new order. Emergence is a key aspect of cognition and learning that has not been handled well by information-processing or radical constructivist theories. Prawat and Floden (1994, p. 43) stated that "it [emergence] represents the most vexing problem for researches in these two camps." The notion of functional emergence, which locates the actualization of a potential in the interaction, is currently finding support in work related to entropy production in self-organizing systems (Bertalanffy, 1952;

Schröedinger, 1945; Swenson, 1997a). It is in search of an explanation and, more importantly, of empirical grounding for understanding the notion of functional emergence that we turn to dynamic constraints, autocatakinetic systems, and the emergence of order.

DYNAMIC CONSTRAINTS, AUTOCATAKINETIC SYSTEMS, AND THE EMERGENCE OF ORDER

To clarify the current state of affairs, beginning with Decartes, the world was separated into an active, striving, end-directed psychological part (that is, the thinking I, or the perceiving mind) on the one hand, with a "dead" physical part on the other. This notion found apparent scientific anchoring in Boltzmann's (1886/1974) interpretation of the second law of thermodynamics (the entropy law), in which the world was said to be continuously moving toward a state of disorder. However, the view that without some external force disorder is the most probable outcome is being challenged by physicists and biologists alike (Bertalanffy, 1952; Prigogine & Stengers, 1984; Swenson, 1989a).

The first law of thermodynamics says that all natural processes in the world constitute transformations of energy and at the same time that the energy of the world is conserved. The second law introduces a second quantity, entropy, which the second law asserts "strives to a maximum" (Clausius, 1865, p. 400) in all natural processes. The energy of the world, to put it as simply as possible, remains the same in all natural processes whereas at the same time the entropy of the world always increases (except when it is maximized, at which point equilibrium occurs and no further changes or processes occur). Many different and confusing meanings have been attached to the word *entropy*, but in its classical sense it refers to the way energy is distributed, and when the distribution is out of equilibrium there exists a "potential" for change or work that comprises flows of these potentials (e.g., chemical, mechanical, or heat), and the second law may be stated equivalently as the fact that the world acts spontaneously to minimize potentials or maximize the entropy. Boltzmann brought the idea of order and disorder to the second law. Modeling a near-equilibrium gas in a box as colliding billiard balls, he noted that with each collision, as the energy became more spread out, the system became more disordered. Extrapolating this model to the world, he argued that the second law was a law of disorder and that the world was always moving toward increasing disorder. The production of order from disorder, he argued, was "the most improbable case conceivable ... infinitely improbable" (Boltzmann, 1886/1974, p. 21), and until quite recently this was the widely accepted view of the second law—a view that made living things and human culture or, more generally, the whole epistemic dimension of the world apparently anomalous or incommensurable with universal law.

But the world is not a near-equilibrium gas in a box, and order can spontaneously "emerge" in open systems. In recent years, Swenson (1989a, 1997a, 1997b; Swenson & Turvey, 1991) has shown that because the world minimizes potentials at the fastest rate given the constraints (the "law of maximum entropy production"), and because ordered flow to satisfy the balance equation of the second law must minimize potentials at a faster rate than disordered flow,[3] rather than order being infinitely improbable, that the world instead can be expected to opportunistically produce as much order as it can. Swenson (1997a) concluded that

> *If* the world selects those dynamics that minimize potentials at the fastest rate given the constraints (the law of maximum entropy production), *and if* ordered flow is more efficient at reducing potentials than disordered flow (derivation from the balance equation of the second law), *then* the world can be expected to produce order whenever it gets the chance. *The world is in the order-production business because ordered flow produces entropy faster than disordered flow.* (p. 37, italics in original)

Coupled with the recognition that the invariant properties of ambient energy flows can proximally specify distal sources ("information" in the Gibsonian sense), this understanding provides the nomological basis for dissolving the postulates of incommensurability and the otherwise disparate rivers and grounding a relational ontology where the epsitemic dimension of the world, knower and known, and their relations can flow directly from universal or natural states of affairs. We further clarify this point in the following section using the concrete example of the Bénard experiment.

Spontaneous ordering is well illustrated by the Bénard experiment in which a viscous fluid (silicone oil) is placed in a dish and heated uniformly from below. As a consequence of the difference in temperature, or gradient, between the hot bottom (source) and the cooler air on top (sink), a potential exists that, following the second law, the system works to minimize by producing a flow of heat from source to sink. Figure 1 shows two time slices from this experiment. The left-hand photo shows the disordered or "Boltzmann regime" where the potential or gradient is below a minimal threshold and the source-sink flow is produced by the random, or disordered, collisions of the molecules. When the potential is increased beyond the critical threshold, however, the situation changes dramatically as spontaneous order arises, breaking the symmetry or homogeneous appearance of the disordered

[3]The balance equation of the second law, expressed as $S > 0$ says that in all real-world processes, entropy always increases. Bertalanffy and then Schröedinger pointed out that ordered flow, which by definition entails a local reduction in entropy, could arise as long as it produced entropy (or minimized potentials) at a sufficient rate to compensate for this internal entropy reduction. Dynamically ordered structures or autocatakinetic systems (and thus all living things), as Swenson pointed out, are thus, necessarily more efficient by virtue of their existence and the imperatives of the balance equation of the second law, at dissipating potentials (or producing entropy).

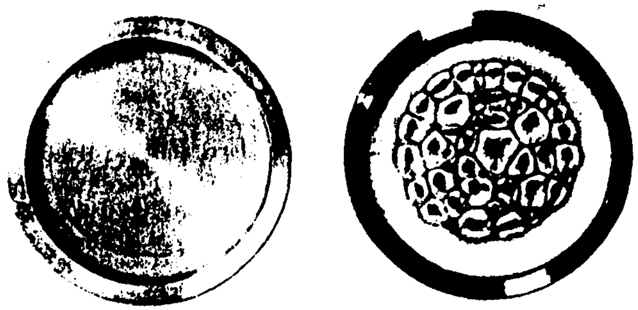

FIGURE 1 The figure depicts two time slices taken from the Bénard experiment. The first slice (left) shows the homogeneous regime where entropy is produced by heat flow from the disordered collision of the molecules (by the process of conduction), and the right side shows entropy production in the ordered regime. Spontaneous order arises when the field potential rises above a minimum critical threshold and stochastic microscopic fluctuations are amplified to macroscopic levels, at which point "hundreds of millions of molecules begin moving coherently together" (Swenson, 1997a, p. 43). Because the emergence of order is thus stochastically (randomly) seeded at the microscopic level, there is great variability during the initial stages of the ordering process. Over time, the system passes through a generic developmental process of selection, including such dynamics as spontaneous fission of cells, until the system achieves a final state of regularly arrayed hexagonal cells (not shown). From "Emergent Attractors and the Law of Maximum Entropy Production: Foundation to a Theory of General Evolution," by R. Swenson, 1989a, *Systems Research, 6*, p. 192. Copyright 1989 by Pergamon. Reprinted with permission by John Wiley & Sons Limited.

regime. At this point, order spontaneously emerges (without explicit instruction from any one component of the system) as hundreds of millions of molecules begin moving collectively together to form an array of regular hexagonal (called Bénard) cells of uniform shape and size (see the right side of Figure 1). Order arises not infinitely improbably, but with a probability of one, that is, every time and as soon as it gets the chance, and with it the rate of entropy production, or the rate at which the potential of the system is minimized or heat is transported from source to sink, increases dramatically. Said another way, in the Bénard experiment, ordered flow (in which we have the emergence and maintenance of regularly shaped hexagonal cells) is more efficient in dissipating potentials than is disordered flow and is thus inevitable.

Beyond overturning the idea that order production goes against universal law, or has to be imposed from without, is the defeat of the idea that the world is explicable purely by efficient or mechanical cause. According to the mechanical view, like causes produce like consequents. In other words, change the initial conditions and the results that follow will be entirely different. In some current literature, there has even been an emphasis on "sensitivity to initial conditions,"

but real-world systems are remarkably insensitive to initial conditions. In fact, epistemic systems, or the intentional dynamics of living things where repetitive tasks or ends are routinely achieved in a world where the initial conditions are never the same twice, completely depends on it. Remarkably, the Bénard experiment shows how, again, the old mechanical view breaks down and how the production of like ends from different initial conditions is an intelligible and usual state of affairs once a richer and contextualized causal framework (the "relational ontology" of autocatakinesis) is recognized. Once spontaneous order breaks the symmetry of the disordered regime in the Bénard experiment, the system goes through a development of macroscopic ordering that ends in a uniform state of regularly arrayed hexagonal flow structures. Because the initial (or microscopic) conditions are never the same twice, unlike antecedents (within tolerance) lead to like consequents. Rather than being "start-specific," to use Dyke's (1997) felicitous terms, the end results are macroscopically determined or "finish-specific."

As counterintuitive as this seems to those socialized under the often hidden Cartesian assumptions that end-directed behavior must be externally or artifactually imposed from the outside—which leads to all the reductios, incommensurabilities, and consequently, and by now well-known, irreconcilable dead-end disputes (e.g., "externalist" vs. "internalist")—a richer ontology makes this fully intelligible, and the older anomalies and the obfuscations they produce dissolve away. There is nothing "spooky" or "magical" in this—in fact, just the opposite. It is Cartesian premises, and the reduction to an impoverished view of reversible colliding particles, that require that illegitimate teleology be imposed from outside. What we now know instead is that to understand what the consequents of efficient cause will be, we need to understand the context in which the efficient causes occur. The same initial conditions or efficient causal interactions, for example, in the Bénard experiment, lead to completely different macroscopic dynamics (viz., disordered vs. ordered) when the system (the context or environment in which the interactions occur) is below as opposed to above a minimal potential threshold, whereas at the same time, different initial conditions when the system is above a minimal threshold lead to the same consequents. These kinds of dynamics are not reducible to start-specificity, but they become fully intelligible once we appropriately contextualize them.

The Bénard experiment shows further the relation between ordered flow and dynamic space–time extension—how ordered flow expands the space–time dimensions of the system and increases the dissipative rate. The transformation of heat from source to sink increases by orders of magnitude as the self-organizing system arises and the individual components begin moving collectively or "cooperatively" together. Because ordered flow thus increases the efficiency of the system as a whole to reduce potentials, ordered flow arises spontaneously whenever energy gradients are above a minimal level. The production of order, in general, and as it can be studied in the example of the Bénard cell we have been using, is instantiated by autocatakinesis (Swenson, 1996).

Autocatakinetic systems are those (a) that continuously self organize, (b) whose global identities are maintained through continuous dynamic activity, and (c) that maintain themselves "by pulling potentials or resources into their own self-production" (Swenson, 1997a, p. 14).

> An autocatakinetic system is a system that maintains its "self" as an entity in relation to, and distinguished from, its environment by a set of nonlinear (circularly causal) relations constituted through the coordinated motion of its components in the dissipation or breakdown of field (environmental) potentials (or resources) (from auto- "self" + cata- "down" + kinetic, "of the motion of material bodies and the forces and energy associated therewith" from kinein, "to cause to move"). (Swenson, 1997b, p. 67)

Autocatakinetic systems refer to a class of systems that exist through and are defined by their exploitation of potentials (resources). Figure 2 provides a schematic of the conjunction capturing the generalized minimal ontology of an autocatakinetic system (Swenson, 1997b). The left side represents the conservation from which the autocatakinetic system and the environment relation emerges, and through which it is maintained. The right side depicts the environment–autocatakinetic system relation. The large arrows represent the irreversible minimization of potential (the production of entropy) in the flow of the energy from the source to the sink (i.e., the gradient between the hot oil and cool air), with the small arrows depicting the continuous circular relations that constitute the autocatakinetic system. It is in this way that the Bénard cells are both productions and producers within the system in which they emerge. Autocatakinetic systems are defined by a dynamic order.

> Their identities are maintained through the incessant flux of their components, which are continuously being replaced from raw materials in their environments and being expelled in a more dissipated form. Persistence (the form of the thing) at one level (the "macro" level) is constituted by change at the component level (the "micro" level). (Swenson, 1997a, p. 19)

The dynamics of an autocatakinetic system provide a principled basis for recognizing the irreducible ecological foundation (minimal ontology) or embedding that characterizes the intentional dynamics of living things (Swenson & Turvey, 1991). Intentional dynamics distinguish the living from the nonliving. Through intentional dynamics that use "information about" and allow for meaningful relations among nonlocal entities, the individual is freed from dependence on those local potentials that constrain the self-ordering of the Bénard cell. In allowing relations extending beyond local potentials, intentional dynamics dra-

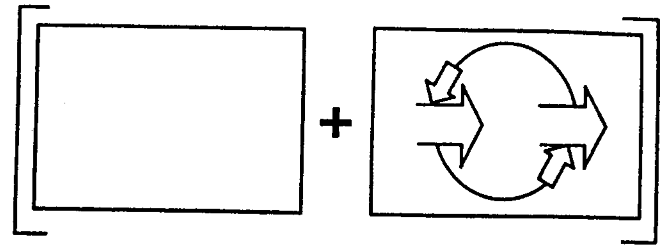

FIGURE 2 A schematic representing the minimal ontology of an autocatakinetic system. The left side represents the conservation from which the autocatakinetic system and environment relation arises. The right side represents the autocatakinetic–environment system relation. The large arrows represent the irreversible minimization of potential, and the smaller arrows symbolize the continuous circular relations out of which the autocatakinetic system arises and is maintained. From "Evolutionary theory developing: The problem(s) with Darwin's dangerous idea," by R. Swenson, 1997b, *Ecological Psychology, 9,* p. 68. Copyright 1997 by Lawrence Erlbaum Associates, Inc. Reprinted with permission.

matically expand space–time dimensions (Swenson, in press-b). Thus, autocatakinesis provides a principled account of how meaning can arise in near and distal contexts.

In contrast to the Cartesian circle (cogito ergo sum) or autonomous circular relations of closed-circle theory that refer only to themselves (consistent with radical constructivist theories), the circularity defining autocatakinetic systems refers to the autocatakinetic–environment relation. Said another way, autocatakinetic systems are *embedded circles* whose existence cannot be separated from their environments either in actuality or by definition. The left side of Figure 3 captures the actuality that autocatakinetic systems do not emerge from "nothing"; rather they come into being through, or in relation to, a particular ground that is neither the system nor that which it is not. Swenson (1997a, p. 23) stated that "there is no existence of self-reference for an autocatakinetic system independent of this relation." It is in this ecological grounding or relational ontology, and the minimal ontology it necessitates, that theories (whether they be about evolution, development, meaning, or pedagogy) predicated on autocatakinetic systems break away from mechanistic and organismic theories alike. There is no meaning in the world outside the dynamics of autocatakinesis. And it is within this ecological grounding that learning can be facilitated.

HUMANS AS NESTED AUTOCATAKINETIC SYSTEMS

Autocatakinetic systems can be contrasted with artifactual systems. Artifacts are typically defined by a set of static components assembled exogenously or by an

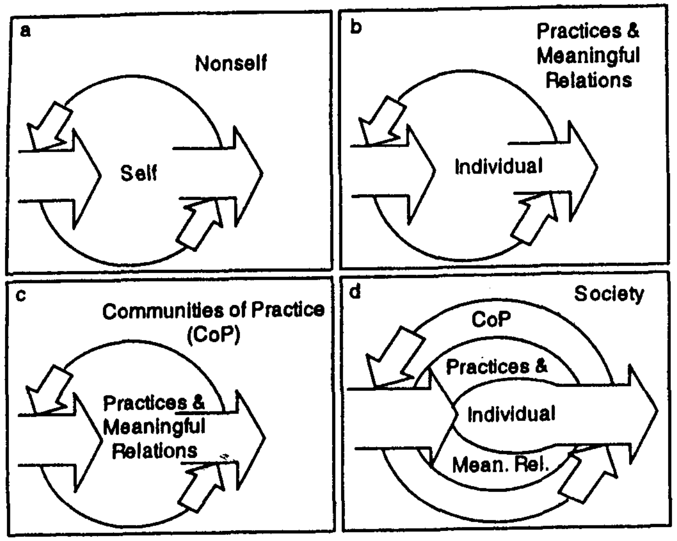

FIGURE 3 A schematic representation of the relations between the self–nonself autocatakinetic system (quadrant a), between the individual–meaningful relations and practices autocatakinetic system (quadrant b), between the meaningful relations and practices–community of practice autocatakinetic system (quadrant c), and among the individual–meaning and practices–communities of practice–society autocatakinetic system (quadrant d). The large arrows represent the irreversible minimization of potential, and the smaller arrows symbolize the continuous circular relations from which the autocatakinetic system arises and is maintained.

external "maker" or artificer (e.g., a car, a hammer, a watch, or a computer). Artifactual systems are consistent with the general model for the machine-world view of Descartes and Newton. In that view, static or recalcitrant components, the learner included, had to be ordered (by applying force, literally) from outside. In contrast, an autocatakinetic (self-organizing) model paints a picture of a world and, we would argue, of knowing, that is inherently active and dynamic, with order arising spontaneously through relation of parts to whole or individual to environment.

Living systems are a type of autocatakinetic system that have replicating components. As in the case of inanimate systems, human development (i.e., the spontaneous production of the self) achieves order through a set of circular relations in which the larger macrostructure constrains activity at the local level, even as local dynamics continue to contribute to global order. Participation in a community is one aspect of this dynamic through which individuals develop identities, framed by and forming the community. In addition, order production takes place as a continuous development toward increasing complexity, a kind

of "build-upism," to use von Bertalanffy's phrase. It is this continuous process of evolving complexity that arises from interactions with the world that Csikszentmihalyi (1993) categorized as the development of self. In contrast to inanimate objects, living systems have the special advantage of being able to receive spurts of energy packets (e.g., food, water, air) that can be stored and used over time. With this "on-board potential," humans are free to stray from a direct energy source while still maintaining their autocatakinesis, through their ability to maintain and create spontaneous order (Shaw et al., 1992). It becomes functional, then, for human systems to seek "information about" their animate and inanimate environments as a means of exploiting remote resources most efficiently in the production of continuously increasing order. From a universal or evolutionary standpoint, the epistemic dimension of the world of which humans are a part is the means the world uses to access higher ordered or otherwise inaccessible regions of space–time.

The degree to which humans can perceive those advantages afforded by their environments is the degree to which they can intend to achieve a formed goal, the degree to which the order-producing process is enhanced through intentional dynamics. It is the interdependence of a system and its environmental resources that creates the conditions for a relation between the system and the context in which it exists. In living systems, this mutual dependence allows for self–other relations at many levels. Figure 3a depicts the mutually defining roles of self and nonself. Figure 3b embeds the individual in the context of socially salient meanings and practices. Meanings and practices are, in turn, grounded in communities of practice (i.e., a collection of individuals sharing mutually defined practices, beliefs, and understandings over an extended time frame in the pursuit of a shared enterprise). All of these ultimately are nested in the larger context of society and the world. Society, as depicted in Figure 3d and used in the context of this article, is defined both as its own autocatakinetic system and as the "other" in the self–other relation of individual humans, the environment in the autocatakinetic system–environment relation.

Similarly, as depicted in Figure 3c, a community of practice is its own autocatakinetic system and can be defined as the "other" (i.e., the context for practices and meanings). By extension, the community of practice can be defined as the "other" in an individual–community relation, with the nested individual-known and known-community relations residing within. Thus, an individual's relations with society are fundamentally spread across various autocatakinetic relations, including the self–nonself, the individual–practices and meanings, the practices and meanings–community, the individual–community, and the community–society relations. Although relations remain nested, schools are faced with the responsibility of exploiting the level of relation that is facilitative for meaningful learning and adaptation within a larger society. Individual communities of practice and their contexts or functional relations with the world are one such framework. Still, it is the role of the facilitator to maintain awareness of all the levels of these nested relations, to support the individual in relation to each, and to maintain awareness that the encompassing, synthesizing intentions reflected in nested autocatakinetic systems make it untenable to separate out the knower and known, the content and context, the individual and society.

Just as there is time asymmetry in all autocatakinetic dynamics, a one-way flow-through of resources (see Figure 2), the development of communities of practice or of the individual is time asymmetric (i.e., dependent on or emergent out of those contexts or events that have come before and that comprise it). The asymmetrical relation extends to the relation between individual and community of practice as well. Although individuals have input into their surrounding communities of practice, the community of practice itself comes with the drawing force of a macrostructure (see Figure 3d). However, no community of practice commands full or final authority. Individuals will find themselves in a variety of communities. Some learners will extend themselves beyond the usual constraints to create innovative dynamics within different systems of a broader and perhaps less widely acknowledged context.

ECOLOGIZING THE LEARNER WITHIN THE AUTOCATAKINESIS THAT MAINTAINS THE COMMUNITY

A community of practice is part of an interdependent system, in terms of the collaborative efforts of its members as well as in terms of the greater and lesser societal systems that make up its nested relations. Being a community member entails being involved in a fundamental way within this dynamic, complexly ordered system, which is continually constituted and redefined by the actions of its members. The individual and the community constitute nested interactive systems, with individuals transforming, maintaining, and being co-opted by the community as they appropriate its practices (Lemke, 1997; Rogoff, 1990). The community transforms and maintains the individual by making available opportunities for appropriation and sustains itself in the process of enculturating its individuals. These transformations of both individuals and communities all take place within the context of society and the world at large, which includes multiple communities of practice and nonsocial affordances.

Communities of practice maintain themselves, in part, because of their specialized practices and their capacity to compile available resources upon which others have come to be dependent (e.g., electricity, food, knowledge).

> Our activity, our participation, our "cognition" is always bound up with, codependent with, the participation and the activity of Others, be they persons, tools, symbols, processes, or things. How we participate, what practices we come to engage in, is a function of the whole community ecology ... As we participate, we change. Our identity-in-practice develops, for we are no longer autonomous Persons in this model, but Persons-in-Activity. (Lemke, 1997, p. 38)

It is the facilitator's role to guide the learner in selecting goals whose satisfaction requires building effectivities that are well matched to, and in some cases expand, those affordances available in the community. In so doing, the facilitator welcomes the learner locally into communities of practice and more globally into society. And, in so doing, individual learners are inducted into the macrostructure of communities of practice and of society, much like smaller, less-ordered individual cells are inducted into the hexagonal shape of Bénard cells.

The process of induction into the community is end-specific. Bénard cells will be formed regardless of the structure of the original, individual cells. At a global level, individuals will be enculturated within a certain tolerance space that sets some constraints on the degree of acceptable variance within its population. These tolerance spaces constrain and structure the probable practices and cognitions that emerge for their members. They serve as macrostructures, akin to Bénard cells, into which the members are inducted. It is important to note that these tolerance spaces, including those defined at the level of communities of practice, are continually emerging anew. To paraphrase Hericletus, one never steps in to the same community of practice twice. Communities of practices, then, mutually and reciprocally, form each other. It is critical to the concept of build-upism (Bertalanffy, 1952) not to reify the nature of communities of practice but to maintain their autocatakinetic essence as one of continual growth and development. The challenge for the facilitator is to seed the learner into this ever-changing dynamic so he or she can become his or her own participant in the flow.

INTENTIONAL DYNAMICS: A SYSTEMS APPROACH TO LEARNING

The assumption that ordering in general, or the development of a more complex understanding in particular, can only occur through some external arrangement of conditions underlies mechanistic theories. In schools, teachers use external contingencies to remove maximal degrees of freedom in an attempt to increase the probability that the student will learn the intended objective (see Rosenshine, 1986, for a discussion of explicit instruction). Further, it is believed that content can be separated from context, departmentalized, and taught as a self-sufficient substance. The irony is apparent: learning without mind, "knowing about" without meaning, meaning without relations.

We have already discussed an alternative set of assumptions in which order is described as emerging within an interaction as a function of the dynamic constraints of the system. Dynamic interactions between living systems and their environments occur in relation to intentions (Shaw et al., 1992). Shaw, Kugler, and Kinsella-Shaw (1990) suggested that intended goals can serve as powerful attractors that constrain the ways in which behavior is organized and dynamically unfolds.

Intentional action is a prime example of how "spread out" cognition is, in that the emergence of an intention requires objects of the environment as well as individuals (Fischer, Bullock, Rotenberg, & Raya, 1993; Newman, Griffin, & Cole, 1989). Intentions, when held, constrain how the system behaves. Order emerges as the system, consisting of an individual in context, moves toward the goal. In this manner, an intention acts to select those boundary conditions that constrain the interior degrees of freedom so that the individual preferentially detects (perceives) goal-related environmental affordances. The processes of intention, detection, action, and constraint toward the "goal state" all become interrelated through the perceiving–acting cycle (see Shaw & Kinsella-Shaw, 1988). Here, achieving fit of an effectivity to an affordance goal is a dynamic process whereby a successful goal path is propagated in such a way that situational specifics are exploited or overcome.

An intention thus provides the boundary conditions that allow the system to become conditionally isolated into a system whose degrees of freedom are functionally constrained to those choices related to the goal (Young & Barab, 1999). Figure 4 is an abstract representation of a conditionally isolated system occasioned by an intention held by the individual in the context of a realizable task goal. The left side of Figure 4 is the space of possible paths available to the individual that could potentially provide access to the intended goal, starting from the learner's initial state. The right side shows how a given current state further constrains the set of potentially successful paths that are available as choices, how a path emerges (and is bounded) as a process of narrowing potentially successful alternatives. Just as bounded thermodynamic cycles give rise spatially to Bénard convection cells, so perceiving–acting cycles, being bounded with respect to a task goal, give rise (spatio-temporally) to subtask cells. The subtask cells parse the total solution path space into alternative subtask path spaces (akin to means-end-analysis). The gray regions displayed in the right side of the figure are the "null regions" of paths that are no longer available to the current goal. They are beyond the possible range of causal action depicted by the edges of the square cells (see Shaw et al., 1997). The figure is designed to demonstrate how an intention brings the individual and goal into a functional synergy, ultimately comprising the bounded set of possible solution paths that, in the language of intentional dynamics, constitute the Omega Cell—referring to the solution space and the boundary conditions by which it is defined (Shaw et al., 1997). This constraint (bounded solution path) is accomplished by means of the learner's autocatakinetics or effectivity, properly situated, that is, that come into being within the context of a particular surround (set of affordances), all of which are occasioned by an intention.

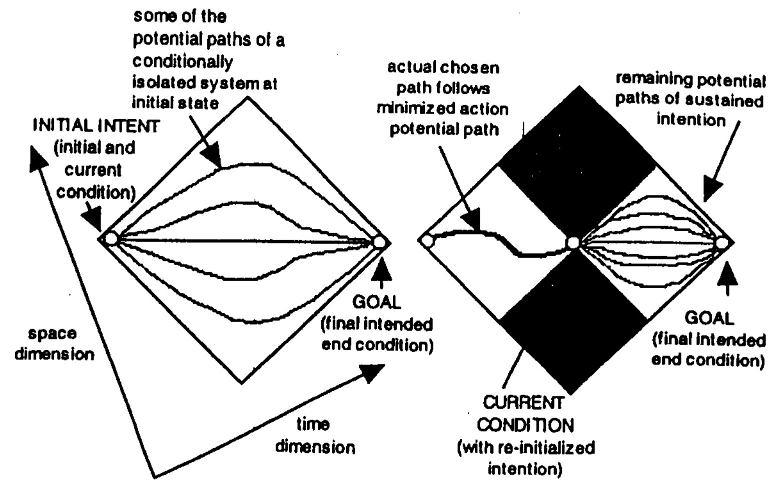

FIGURE 4. Abstract space representing the emergence of conditional isolation by an intention. The left side represents the space of possible paths available to the individual that could potentially provide access to the intended goal, while the right side shows how a given current state further constrains the set of potentially successful paths that are available as choices.

Swenson's (1989a, 1991, 1997a, 1997b, 1997c) description of systems evolving into a more highly ordered flow as a function of their dissipative potential provides a lawful explanation for such processes. Turvey and Shaw (1995) stated,

> Material systems [such as humans] with the property of "knowing about" can interact in more diverse ways with their surroundings than material systems restricted to force-based interactions, extending, thereby, the opportunities for the global system to degrade energy. Colloquially, one would say that the interactions between organism and surround typifying "knowing about" are information-based." (p. 157)

The intentional dynamics of living things provide the means to sustain autocatakinesis between discontinuously located (nonlocal) potentials (those informationally specified) with respect to available goal paths (i.e., formal causes) in the development of space–time (Swenson, in press). Nonlocal potentials are those whose realization is not immediately available but are environmentally specified via "information about" (i.e., about possibilities for action). This information about specifies an *opportunity* for action (affordance) for those individuals with the requisite *means* (effectivities). Recall that an effectivity is the realization of a goal (affordance)-directed biological function. Hence, the goal in relation to individual effectivities specifies nonlocal boundary conditions for which biological processes (i.e., metabolic functions—e.g., ATP cycle) must provide local, self-produced steps down a possible goal path. That is, a goal anticipates its antecedents.

It is important to note that goal-directed systems are not being merely self-directed toward goals but are directed *by* goals. These goals set up a path, or a bundle of virtual paths (mathematically described as a germ), to be perceived and acted upon by the individual (Weir, 1984). As such, "a goal is not a designated final state to be reached by a system but a distinctive way for the system to reach a final state over one of several optional paths, given goal variation" (Shaw, 1987, p. 243). The goal in relation to the individual's potential effectivities actually defines the potential goal paths depicted in Figure 4. By creating a relation between self and nonlocal resources, intentional dynamics

> constitute a development or instantiation of space–time ... that reduces otherwise possible worlds to actual possibles. The more laws or invariant properties that are understood or the deeper the understanding the more otherwise possible worlds are collapsed onto actual states of affairs. (Swenson, in press, pp. 11–12)

It is in this manner that the goal, if adopted by the individual, affords the extension of the autocatakinesis of the learner. The message for the facilitator is to support the learner in recognizing the invariant properties that characterize the intention. As this happens, possible goal paths begin to collapse into one, and learning is very nearly inevitable.

The particular configuration of the system will be characterized by those sets of effectivity–affordance couplings that most efficiently satisfy the intention. Said another way, the system is maintained and constituted by the (dynamic) coupling of individual effectivities and environmental affordances, which together constitute the boundary conditions, again in the service of intention. As such, the process is not governed by an efficient cause, and there are no seemingly recalcitrant particles (learners or facts) needing to be ordered, as in the Cartesian or Boltzmannian view (and didactic models). Rather, the ecologized, or autocatakinetic, model assumes that (under the appropriate conditions) the particles (learners), in effect, "want" to or are propelled to learn once the intention has been properly initialized. The role of the facilitator is to steer the learning system toward an *appropriate* intention, one that can be held meaningfully by the learner, one that aids him or her in detecting the invariance amidst the variance. At this point, no further external contingencies are needed.

This perspective grounds or ecologizes the effectivities of the learner (i.e., skills, practices, understandings) in the affordances of the environment (i.e., artifacts, resources, tools, goals). Returning to the ontology described previously (see Figure 3), the notion of teaching abstracted skills, practices, or understandings without pulling knower and known into a single system would be, on this

view, untenable. A minimal ontology, therefore, must include a system consisting of effectivity–affordance couplings—couplings that occur in the service of an intention.

The critical role of intention in learning is its ability to set the focus of attention, isolate it from all other potentially distracting influences, and serve as an attractor around which behavior can organize. This concept of intention is something more than desire (i.e., motivation). Motivation would certainly not be a sufficient impetus toward the goal if the learner does not perceive what it affords. Motivation in the absence of a well-held intention may take on the appearance of frenetic scurrying in multiple directions. Behavior is energized without the organization, that is, without conditional isolation established by the intention. From a pedagogical perspective, there are clearly dangers of attempts to increase motivation when the learner cannot share the instructional intention (Cherkes-Julkowski, 1996, 1998).

Effective instruction, therefore, involves the establishment of an environment that affords interactions within which the individual develops intentions that in turn create the inspiration and constraints for the development of specific practices (effectivities), ultimately expanding the autocatakinetics of the learner to draw upon further environmental affordances. Such a process cannot be abstracted out of the particular effectivity–affordance couplings or from the contextualized experience in which, and for which, it emerges. Systems dynamics of this kind suggest an alternative to the traditional view of transfer of learning, according to which the learner abstracts (constructs) a more generalized (idealized, symbolic) view. Instead, "transfer" might be thought of as a more responsive enterprise in which the learner has come to recognize invariant properties across a range of instantiations. Each variation seems to dramatize that which is most essential. Without participation in multiple contexts, these linkages cannot be made.

THE PROCESS OF ENCULTURATION: CHANGING THE AUTOCATAKINETIC SYSTEM OF THE INDIVIDUAL THROUGH PARTICIPATION

If one adopts a self-organizing view of human development, the role of instruction is to aid the learner in developing those practices that maintain, and ultimately expand, the learner's relation to available resources. Although some environmental affordances may be detected directly, the exploitation of select community affordances frequently requires guidance in attuning to community-specific meanings and practices. For the individual to understand his or her culture, the initial objective is to attune his or her perspective so as to provide greater overlap with that of the community, thereby seeding those dynamics that bring the learner and community into a functional system. This process of enculturation, then, involves participation in (becoming a part of) the practices, problems, and issues that exist in the larger community of practice. The learner develops understanding (knowing about) and meanings in context and through his or her actions within that context (Dewey, 1963; Tanner, 1997). This can be contrasted sharply with the traditional practices of schools, which focus almost exclusively on acquiring predefined knowledge. In this traditional view, individuals identify and perhaps define words that people in the community use for particular situations, but they do not necessarily apprentice in their use or value their function or the situations in which they are functional.

As facilitators ground that which is being learned within the emergent tolerance spaces (participant structures) of a community of practice, they provide learners with the opportunity to participate in the function of those community structures. The learner develops what Focault (1975) referred to as a *gaze*, meaning the manner in which experts in a domain perceive domain-related situations (Hay, 1993). For example, when an architect enters a building, he or she will immediately perceive structural aspects that may go undetected by a lay person. Access to similarly deep levels of enculturation cannot be handed to the learner; rather they require participation in community-defined practices in relation to personally meaningful problems—it is different to describe or even to observe the production of the hexagonal shapes of the Bénard cell than it is to be one.

The relation that emerges when individual and environment become part of an autocatakinetic system brings otherwise incommensurables together and thus provides the mechanism for learning in context. When learners develop community-based intentions and participate in their fulfillment, the resultant relation "encompasses and gives meaning and value to the subject matter, the process of learning it, and its relations with the learner's life and activity more generally" (Lave, 1997, pp. 33–34). The more the teacher, the texts, the curriculum, the lessons "own" the problems or decompose steps so as to push learners away from participation within an autocatakinetic system emerging around the problems, the more difficult it may be for students to develop the practice. For, in a very real sense, it is not possible for students to resolve problems that are "someone else's" and that exist "out there" (Lave, 1997). And, when the learner participates in practices to address community-based intentions, he or she becomes, at that moment, an enculturated, participatory, contributing community member—that is, the learner's and the community's autocatakinesis overlap.

As with any autocatakinetic system, even the initial specification of community practices is a process that is not external or solely top–down, not solely a global structure determining a local one, and not a community of practice acting as an efficient or mechanistic cause for the individual. It is important to reestablish our conviction that emergent practices and meaningful relations are continually created anew and that communities of practice are subject to the same macrodeterminancy as individuals.

CONTEXTS OF LEARNING IN THE ECOLOGICAL PARADIGM

Communities of Practice

Predicated on the belief that practices and meanings emerge only when fully contextualized, many educators are looking toward building communities of practice as contexts through which learning will occur. Although Lave (1993, 1997; Lave & Wenger, 1991; Wenger, 1998) has brought the most focused attention to the concept of communities of practice, she has done so through an anthropological perspective, with an examination of practices in everyday, out-of-school society. In fostering the development of contexts specifically designed for learning, we are still in our infancy with respect to understanding what constitutes a community of practice and whether we can legitimately capture its essence within the walls of schools. For example, Brown and Campione (1990) proposed the design of *communities of learners and thinkers*, Lipman (1988) proposed *communities of inquiry*, Scardamalia and Bereiter (1993) proposed *knowledge building communities*, the CTGV (see Barron et al., 1995) proposed *learning communities*, and Roth (1998) proposed *communities of practice*. We argue that although these projects clearly capture much of the richness of out-of-school environments, they frequently fall short of constituting autocatakinetic systems with self-replicating components functioning as part of a larger social context—characteristics of communities of practice outside of schools. These school projects have been designed primarily for students, with outcomes that are without immediate value to society—in other words, for many students they remain worlds unto themselves. However, to the extent that they support the opportunity for students to set intentions within meaningful contexts, and to the extent that they are of value/benefit to the student as least as much as benefit to the community or society, we view these projects as valuable steps forward. Further, with respect to the context of schools, these learning environments frequently represent the most feasible possibilities for contextualizing emergent practices and meaning within activity. Therefore, we will briefly indicate some of the advantages of learning within these contexts.

These projects cast students as participants in a social and material context. As students adopt situation-relevant intentions, their participation is constrained by the attendant boundary conditions. To the extent that these projects bind would-be-knower and known into an autocatakinetic relation, they provide the basis for meaning. In contrast to didactic instruction, intentions emerge in the context of student participation and thus come with ready-made potential for meaningful relations. As they participate in a specific learning community, students have access not only to its meanings and practices but also to those more expansive meanings and practices inherent in the larger, more encompassing structures.

Establishing Practice Fields

The practice field is a metaphor introduced by Senge (1994) in relation to the practice field of sports where students prepare for the big game. It refers to learning contexts that are separate from the real field and in which learners can practice the kinds of activities that they will, potentially, encounter in the real world. These activities are situated within a context that has many of the environmental circumstances and surroundings that would be present had they been working on the problem in the context of the community that addresses this problem (Barab & Duffy, in press). The design of rich practice fields has received much attention over the last decade (Barab & Landa, 1997; Barab, Hay, et al., in press; CTGV, 1990, 1993; Edwards, 1995; Hannafin, Hall, Land, & Hill, 1994; Hmelo & Evensen, in press; Kommers, Grabinger, & Dunlap, 1996; Koschmann, 1996; Roth, 1996, 1998; Roth & Bowen, 1995; Reigeluth, 1999; Ruopp, Gal, Drayton, & Pfister, 1993; Young & Barab, 1999), and there have been many lists of principles for design of these learning contexts.

Problem-based learning (PBL) is an example of one approach to establishing practice fields. PBL, which has its roots in the medical profession, involves presenting students with real, but historical, patient cases to diagnose (Koschmann et al., 1996). PBL has extended beyond the medical profession to include business schools (Milter & Stinson, 1995), elementary and secondary schools (Hmelo & Evensen, in press), higher education, and a host of other areas. Central to all of these instances is the goal of presenting students with "real" societal, business, or educational problems. The PBL approach differs from studying cases (Williams, 1992) in that the students in PBL environments are responsible for developing their position on the issue (their solution to the problem), rather than studying someone else's solution. Further, they are expected to identify what it is they need to know and learn to develop a solution, with problem-related "learning issues" being generated by the students (Koschmann, Glenn, & Conlee, in press). Thus they are engaged as if they were in the real world working on this problem, and there is an emphasis on increased ownership.

Anchored instruction, as advanced in the work of the CTGV (1990, 1993), represents another approach to creating practice fields. As with PBL, the goal is to capture a real problem and the context for that problem is drawn from the real world. In contrast to PBL, however, there is no pretense that this is a real problem. Rather, the learners are invited to engage in a fictitious situation that is occurring in a simulated real-world environment. Rich and realistic video contexts are provided not only to provide the information relevant to working on the problem but also to create the fictitious context. If the students buy in to the proposed problems, then they will be engaged in some of the same sorts of problem solving in which the people in the simulation video would engage.

In properly designed practice fields, practices and meaningful relations emerge due to their functional value for task participation (Barab, Hay, & Duffy, 1998). These learning contexts provide sharp and useful contrasts to typical didactic learning in which the instructor imparts abstracted and frequently meaningless descriptions. However, in spite of their contextualized advantages, practice fields such as PBL environments or the work of the CTGV may be less effective in conditionally isolating the system than the real thing. Any time information is transferred out of its natural context, made more remote and disembodied from the learner, its meaning is made more elusive. Where context would have provided the constraints necessary for a conditionally isolated system in which learner and goal are bound together into a functional synergy, isolated classroom experience places a large demand on the teacher continually to contrive those constraints that will force the learner toward the goal. In the end, this creates more work for everyone, especially the teacher, and places the learner at unnecessary risk of missing the point.[4]

In summary, although the goal in designing practice fields is to make the situation as rich as possible so that it simulates the conditions found in real-world situations, within the context of the classroom, designers are forced to make some decisions that exclude opportunity for full structural constraints and dynamics, for example, lack of true experts, lack of access to situationally responsive stimuli (e.g., the pertinent resources must be preassembled), and lack of functional outcomes that confer meaning on practice. As a result, many of the boundary conditions are not in place and, therefore, the system may not become conditionally isolated without the teacher's support. This challenges the facilitator to maintain some influence over the boundary conditions without interfering with intentional dynamics. We contend that the key element in doing this is to focus on the learner's adoption of the goal, that is, on seeding the intention.

SEEDING THE INTENTION: BUILDING DYNAMIC SYSTEMS

Effective instructional interactions can be said to have occurred when the learning episode embodies a degree of dynamic stability, the learner and facilitator share a goal, and learners participate in an instructional goal that organizes their thoughts and actions in its pursuit. Once they function within a single system, the original

[4]Clearly some classroom presentations are more effective than others (see Koschmann, 1996, for some examples). If the learner has some prior, contextualized experience, classroom instruction is likely to be more meaningful. Or, for some newcomers (individuals who previously felt no membership to a community of practice), experiences with the PBL context may serve as an impetus to become a part of a particular community of practice. However, all too often these connections are the exception and not the rule.

goals held by the learner can interact dynamically with those held by the facilitator. Although the facilitator may have had a goal that directed the emergence of the shared space, ultimately, no one is in charge here. Neither participant solely sets the agenda. Each contributes to the construction of the boundary conditions that ultimately evolve. The choreography is emergent, as are the goals. The joint adoption of a shared or mutual intention requires a functional synergy between two or more cooperating team "players" (Smith & Smith, 1987). It is at that point that the actions of the participants are jointly mobilized around the path toward the currently held goal. It might be said that the participants are inside the same conditionally isolated system, the "construction zone" (Newman et al., 1989).

However, as stated previously, it is not the learner–facilitator coupling that is the ultimate purpose. Of prime importance is that the learner becomes coupled with the autocatakinesis of the learning context. It is the intention that couples learner and environment, serving to conditionally isolate the system and make certain participation paths more likely. Unlike departmentalized knowledge that has been abstracted and taught to the student by the teacher, a systems approach acknowledges that meaningful relations emerge through situated activity. It is the responsibility of the learning facilitator, drawing on his or her experience, to aid the learner in adopting those goals that most effectively attune his or her attention to community available resources—or abandoning the goal if the learner is in the process of establishing an equally viable alternative goal that is personally meaningful or of broader relevance.

As a result, intentions are not merely shared. They may be of greater intensity for the learner. They might be broader for the facilitator than for the learner because the facilitator has more overlapping relations with the culture and with aiding learners in the enculturation process; therefore, it is the facilitator's responsibility to recognize pitfalls and to provide corrective feedback. Facilitators are guided by their membership in a series of nested communities (i.e., school, town, society, alternative communities, as well as prior experiences) but are effective only to the extent that they use their authority justly and to the extent that they can respond to their learners. The facilitator is a vestige of the larger culture and, as such, a field resource from which the learner can draw. Thus, the interaction is asymmetrical often with the facilitator having the responsibility of initiating the learner into those practices (including knowing about) and meaningful relations that are reflective of the types of relations occurring outside the school. However, one is not simply "schooling" the learner in terms of adopting cultural norms; rather the facilitator aids the learner in engaging in practices and exploiting available resources for the learner's own self forming, a process that not only expands the space–time dimensions available to the learner as system but also has the potential to expand the space–time dimensions of the facilitator and of those nested communities of which both are and will be a part. As long as a (any) joint intention maintains the learner and facilitator within the same goal-anchored system, the facilitator has the potential to influence the learner from within that conditionally isolated system, which is where, we argue, that true expertise emerges. We have come to believe that the coupling of learner and environment requires a solution path that is uniquely emergent from within the learner's ecosystem and cannot be prescribed for the learner, independent of contextual particulars. When the learning situation fails to transcend the constraints associated with schools (e.g., teachers' approval, grades, good jobs), there is a missed opportunity for a direct relation between knower and known.

Instruction should then begin with a goal that can be mutually held, one that reflects a merging of the curriculum and the learner's preexisting propensities. The facilitator must create the mechanism for this to happen—that is, supply constraints of a kind and intensity adjusted to the learner's current state and assist the learner in reaching an ever-evolving instructional goal. Once a merger across individual systems is achieved, the novice has access to the experience and awareness of the expert. However, the situation is delicate. Instruction must be well modulated, suited to the current tolerance of the learner. Constraints that are too strong threaten the potential for mutuality and may send the learner into a highly energized state and ultimately decreased organization (Cherkes-Julkowski & Mitlina, 1999). Constraints that are too weak fail to provide the impetus for higher levels of self-organization (Guess & Sailor, 1993). The facilitator, then, also serves as a regulatory agent within the conditionally isolated system.

CONCLUSIONS

Modern science has been built on a Cartesian or Newtonian (mechanical) paradigm. This paradigm, built out of the Cartesian legacy in which there was the separation of individual and environment, has contributed to an artifactual view of mind in which learning is conceived as either the acquisition of objective, external structures from the world or the building of mental, internal representations in the mind. Rather than placing meaning, cognition, or knowledge in the environment as separate from the individual (as is frequently associated with objectivist views) or in the minds of learners as separate from the environment (as is frequently associated with constructivist views), we have advanced a relational ontology. In contrast to autonomous circular relations of closed-circle theories that refer only to themselves (i.e., theories that treat the individual or the environment in isolation), the circularity defining autocatakinetic systems refers to the autocatakinetic–environment relation. Building on the previous work of Swenson (1989a, 1997a, in press), we have argued that these systems come into being through, or in relation to, a particular ground that is neither the system nor that which it is not, and that there is no existence of self-reference for an autocatakinetic system independent of this relation. It is in this way that we have discussed knowing about, meaningful relations, and cognitive activity as fundamentally situated, that is, as part of a particular ground (context).

Drawing on theories of self-organization, we have argued that order is not something that the instructor brings to the learner; rather, it continuously emerges through an autocatakinetic process within the learner–environment system. We have argued that such system dynamics underlie (among other relations) the emergence of communities of practice, as well as the identity and functioning of individuals living within the community. Our explanation of autocatakinetic systems implies that any component, whether we are referring to a practice, individual, or community, must be considered in relation to the "other" through which it emerges (see Figures 2 and 3). Significance, then, does not exist in any one component (i.e., the individual or any other parsing of the dynamic relation); rather, it is spread across the various components in relation to the task at hand. On a related note, learning is not simply the acquisition of a set of preprocessed facts. Rather, we have argued for the necessity of each individual's *participation* in the creation and functioning of his or her idiosyncratic learning experience, *as part of* an autocatakinetic system.

We have argued that educators need to establish trajectories that move student experiences from the classroom only (or even the PBL space) to real-world contexts in which what students are learning/doing takes on meaning because they receive natural feedback at all points along the way, including identifying the problem and progressing toward its resolution. Practice fields are designed to afford the emergence of contextualized practices and meanings, but they do so in the limited context and in the dynamics of schools. Although it is possible to contrive "realistic" problems that share many important attributes of real-world problems (Young & McNeese, 1995), they may form a conditionally isolated system with the learner where school-assigned meanings become the goal—complex problems are solved to get a good grade, completed for the purpose of satisfying a teacher or parent, not for the functional purposes for which these practices initially emerged. Once the problem is removed from its actual context and the intention migrates from problem solution to exploitation of institutional rewards (rather than exploitation of functional affordances), the quality of the system changes. This change has the potential of also altering the nature of the practice and the meanings that emerge.

We have tried to demonstrate how adoption of the goal embodies its own path to goal attainment; that adoption of a goal or intentionality in general is the manifestation of an autocatakinetic system in which the self–other, knower–known relation is maintained in a conditionally isolated system and that adoptable goals arise in contexts in which detectable invariance can be discerned. As such, a particular learning context is not meaningful or authentic because it is deemed so (Barab, Squire, & Dueber, in press); rather, meaning arises within (as part of) context (as meaningful relations), and it is the responsibility of the educator to support (scaffold) the learner in developing relations with the learning situation in particular and society in general. This is consistent with Dewey, Peirce, and others who argued for the necessity of experience. However, as Dewey (1925/1981) also argued, not all experiences have the same educational potential. Learning can occur anywhere, but deeper levels of enculturation involve full participation within systems that have relations with, are nested within, still larger systems.

We have outlined some of the key assumptions of an ecological paradigm, highlighting individual–environment relations and the importance of grounding learning in terms of its ecological function. Such discussions provide a foundation from which to conceive the method and goals for learning and instruction. The old Cartesian–Boltzmannian artificer view in which the particles (learners) were recalcitrant and requiring external ordering (didactic instruction) is demeaning and ineffective. Schools are not simply responsible for the imparting of knowledge. We have suggested that educators have the responsibility of seeding learners into those conditions in which they can become active participants and can thus adopt meanings and practices that best extend their own functioning and, in turn, their autocatakinetic development. Each development of this kind provides the basis for subsequent, higher order evolutions (Swenson, 1997c, 1997d).

IMPLICATIONS

Our intention in writing this article was *not* to advance a prescriptive approach for instructional designers. Rather, it was our intention to offer a principled *explanation* for how learning takes place through the individual–environment relation. Previous accounts have been lax in weeding out not-so-hidden dualisms (e.g., how the individual can be brought to the world in objectivist/materialist ideology) and confusions (the problem of arbitrary constraints in both didactic instruction and in narrowly defined situated learning contexts). An adequate explanation for the self–other relation that is fundamental to learning has to be grounded in natural law that can account for how such relations form and order themselves. The ensuing challenge, of course, is to infer, from a principled account of learning, what form instruction would need to take.

Throughout much of one's life, and especially in schools, one spends inordinate amounts of time experiencing preprocessed information—being handed descriptions of practices and meanings that were part of other people's autocatakinetic systems. Schools may be thought of as most culpable in terms of relegating learning and instruction to processed information (delivered through didactic lectures and textbooks) at the expense of engaging learners in experiences through which practices, meanings, and ultimately identities emerge.

When official channels only offer possibilities to participate in institutionally mandated forms of commodified activity, membership, participation, and genuine access to information are rare (Barab & Duffy, in press). As a result, children can develop identities only in relation to their ability to engage in commodified activities directed toward the production of grades (Walkerdine, 1997). For some students—"good students"—this helps enculturate them into the identity of a "successful" student. Some truly effective students are able to break away from these restrictions and form their own relation with the material. But for many others this context results in the "widespread generation of negative identities [under-achievers, failures]," as well as the emergence of "institutionally disapproved interstitial communities of practice [burnouts, trouble makers]" (Lave, 1991, pp. 78–79). Despite the school's effort to use the constraints of curriculum and discipline to direct recalcitrant students to the "preferred" goal, it is frequently their relation to alternative communities of practice that are the most personally transformative.

We hope that educators and researchers will continue to explore ecological methods for carrying out research and instruction that are predicated on self-organizing, not mechanistic, assumptions. In our opinion, such efforts will eventually redefine old and introduce new practices and methodologies that have the potential to transform the view of education as we now understand it—from one of acquiring programmed responses to one emphasizing active participation as part of a dynamic system. However, this move does not simply entail shifting from one dualist perspective to another (objectivist to constructivist) but involves adopting a relational ontology that draws on and couples individual and environment to the context in which they are grounded. This way of thinking requires the abandoning of the more traditional Cartesian dichotomies and the adoption of a relational ontology. If we cling too tightly to previous assumptions, we run the risk of ending up trapped like the monkey, eventually limiting our own opportunities and those of our students to see, to interact with, to become a part of, and to potentially change the world in meaningful ways.

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Addressing the Challenges of Inquiry-Based Learning Through Technology and Curriculum Design

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Inquiry experiences can provide valuable opportunities for students to improve their understanding of both science content and scientific practices. However, the implementation of inquiry learning in classrooms presents a number of significant challenges. We have been exploring these challenges through a program of research on the use of scientific visualization technologies to support inquiry-based learning in the geosciences. In this article, we describe 5 significant challenges to implementing inquiry-based learning and present strategies for addressing them through the design of technology and curriculum. We present a design history covering 4 generations of software and curriculum to show how these challenges arise in classrooms and how the design strategies respond to them.

> Students at all grade levels and in every domain of science should have the opportunity to use scientific inquiry and develop the ability to think and act in ways associated with inquiry. (*National Science Education Standards,* National Research Council [NRC], 1996, p. 105)

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