Curriculum-Based Ecosystems: Supporting Knowing From an Ecological Perspective

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The goal of this article is to advance an ecological theory of knowing, one that prioritizes engaged participation over knowledge acquisition. To this end, the authors begin by describing the environment in terms of *affordance networks:* functionally bound potentials extended in time that can be acted upon to realize particular goals. Although there may be socially agreed-upon trajectories specifying the necessary components of a network activated for realizing a particular goal, the particular network engaged by an individual is dependent on adopted intentions and available *effectivity sets,* the attunements and behaviors that an individual can enlist to realize an affordance network. Thus, to help clarify the challenges of connecting learners to ecological systems through which affordance networks are activated, the authors use the term *life-world,* which refers to the environment from the perspective of an individual. Building on their characterization of affordance networks, effectivity sets, and life-worlds, the authors offer an ecological focal point for curricular design.

Consistent with the knowledge-acquisition metaphor and with the current focus on standardized test performance, we have seen inordinate quantities of resources focused on assessing the outcomes of learning. Standards provide a useful list of some core disciplinary formalisms that all learners need to know, but they provide little guidance on how one should best support people who are coming to know. Notwithstanding the recent National Research Council report on *How People Learn* (Bransford, Brown, & Cocking, 2002), we have much to learn about the role of context in motivating learners and in altering the very meanings one develops with respect to the content being taught. It is one thing to learn about the concept of erosion to pass a test (having *exchange* value) and quite another to use it as a conceptual tool (having *use* value) for understanding why the water quality of a local river is deteriorating (Lave, 1988). Situativity theorists have made clear the distinction between knowledge (e.g., facts or concepts) as "acquired" for a test, and knowing as participation in rich contexts where one gains an appreciation for both the content and the situations in which it has value (Brown, Collins, & Duguid, 1989; Greeno & Moore, 1993; Lave & Wenger, 1991; Sfard, 1988).

In fact, from a situated learning perspective, it makes little sense to speak of the content, function, setting, and acting person as independent of one another (Lave, Murtaugh, & de la Rocha, 1984).

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Central to the situative perspective is the belief that one should abandon the treatment of concepts as self-contained entities and instead conceive of them as tools—tools that can be fully understood only through use. The central tenets of this perspective with respect to knowing are that (a) knowing is an activity—not a thing; (b) knowing is always contextualized—not abstract; (c) knowing is reciprocally constructed in the individual–environment interaction—not objectively defined or subjectively created; and (d) knowing is a functional stance on the interaction—not a "truth" (Barab & Duffy, 2000). Many situativity theorists have further emphasized the reciprocal character of the interaction in which *individuals,* as well as cognition and meaning, are considered socially and culturally constructed (Heidegger, 1996; Lave, 1993; Lemke, 1997; Leont'ev, 1978; Walkerdine, 1997; Wenger, 1998).

Consistent with the situativity perspective, we argue for an ecological theory of what it means to know. Such a theory acknowledges the world as being structured to support goal-directed behaviors, while at the same time placing the realization of these meanings as part of the individual–environment relation. We view the environment as meaningfully structured; that is, functionally bound in a manner that supports and even specifies numerous possibilities for action for those individuals with the requisite experiences and intentions (Barab, Cherkes-Julkowski, Swenson, Shaw, Garrett, & Young, 1999; Bertalanffy, 1952; Prigogine & Stengers, 1984; Swenson, 1989). Situating knowing and meaning as part of individual–environment relations, rather than solely in the world or in the individual, both simplifies and complicates the challenge for schools. When educators fail to engage students in meaningful relations and instead impart core ideas as isolated facts or abstract concepts, these facts and concepts are no longer connected to the situations that allow them to be powerful tools in the world. The core disciplinary formalisms (facts, concepts, practices, methods, principles) run the likely risk of becoming disembodied and effectively disconnected from any meaningful use in the world. Consistent with Nathan's (2005, p. 5) discussion of disciplinary formalisms, we are referring to the "formal structure and abstract principles that underlie the conceptual framework of the content area." The irony is that we then wonder why children appear unmotivated to learn after we have disconnected meaning from the learning situation, assuming that the learner somehow will attribute the same functional value to the information as the teacher does.

It is in response to this problem that we argue for an ecological view of learning and participation, one that allows content to *live in* its contextual richness with a focus on helping students attend to those underlying, invariant structures that also have cross-contextual value (Barab et al., 1999). In essence, we believe that "the place to look for meaningful content is not in the normal

physical descriptors of individual particles [nor in the individual], but instead in the variables of the flow itself" (Swenson, 1999, p. 21). It is within this coupling of individual and environment, in the flow itself, that ecological psychologists locate meaning and intelligent action (Barab & Plucker, 2002). From this ecological perspective, learning is a process of becoming prepared to effectively engage dynamic networks in the world in a goal-directed manner (Hoffmann & Roth, 2005). Getting learners to adopt those goals for which these networks have value constitutes an additional challenge beyond helping them to engage the perception–action cycles associated with actualizing a particular network; that is, it is one thing to "know" something in order to pass a standardized test and quite another to function in those situations in which the knowledge has value and still another to choose to engage in these situations (Whitehead, 1929). Like Gibson (1986), who pursued a notion of perceptual *affordances* in the environment, described as possibilities for action taken with respect to an individual, we are interested in helping students to engage *affordance networks*—especially those that have been deemed as significant to functioning in the world.

Affordance networks, in contrast to the perceptual affordances described by Gibson, are extended in both time and space and can include sets of perceptual and cognitive affordances that collectively come to form the network for particular goal sets. Affordance networks are not entirely delimited by their material, social, or cultural structure, although one may have elements of all of these; instead, they are functionally bound in terms of the facts, concepts, tools, methods, practices, commitments, and even people that can be enlisted toward the satisfaction of a particular goal. In this way, affordance networks are dynamic sociocultural configurations that take on particular shape as a result of material, social, political, economic, cultural, historical, and even personal factors but always in relation to particular functions. The particular shape of a network changes with the dynamic interplay of these factors; thus, for example, a network related to enacting democratic principles will be different for various groups or even for the same group on different occasions. Or, to use an example fairly close to home, what counts as "evidence-based" research under one administration might involve a very different network under a different one. In addition, while there may be socially agreed-upon networks determining the components necessary for effectively accomplishing a particular task, the specific network enlisted by an individual is dependent on his or her perspective in terms of what constitutes the network. For a key bounding on the shape of any network for a particular individual is the effectivity set through which she comes to form relations with the network. To be clear, enacted networks for any individual are bound by socioculturally determined affordance networks, individually engaged effectivity sets, and adopted goals and intentions.

To help clarify the challenges of connecting learners into ecological systems (i.e., coupling effectivity sets and affordance networks), we enlist what others have referred to as *life-worlds.* These can be thought of as the environment for an individual described in terms of the customary ways of structuring the activities that take place within it (Agre & Horswill, 1997; Schutz & Luckmann, 1973). Thus, a life-world contains those objects and (social and material) phenomena that are salient *to the acting individual* in part because of her current goals and intentions and in part because of her having the requisite effectivity sets. Whereas two people can share a physical space, it is a rare case indeed for two people to share a life-world. Here, we discuss life-worlds as emergent phenomena, with their particular shape being a result of the affordance network/effectivity set coupling, and their goals being an essential factor contributing to whether a particular network becomes enlisted in supporting the emergence of one's life-world.

More to the point of this article, it is one thing for a curriculum designer to develop a context to support the acquisition of some formal content. It is quite another to establish a context that has the potential to connect the learner into a larger network of possibilities. It is still another to develop it in a way that engages an individual to the point that his or her life-world is expanded to include more complex networks, thereby supporting richer potential for more expansive affordance/effectivity couplings. The purpose of this article is to advance an ecological view of knowing: we first define *affordance networks* and *effectivity sets* and then clarify the notion of *life-worlds* and the challenge of supporting overlapping relations between socially agreed-upon affordance network/effectivity set couplings and those that emerge for any individual. The notions of affordance networks, effectivity sets, and life-worlds assist us in clarifying a focus for education and the challenges in making it happen for individual students. Toward this end, as the final goal for this article, we advance the notion of curriculum-based ecosystems as a partial solution to supporting the emergence of meaningful relations in the context of schools.

An Ecological Theory of Knowing

Affordance Networks

James J. Gibson and colleagues have conducted numerous studies that demonstrate how the environment perceptually specifies possibilities for action (chairs as sittable, doorways as passable, platforms as crawlable, etc.). Central to their work is the belief that the environment includes qualitative regions of functional significance (affordances) that are visible to individuals with reciprocal skills (effectivities) and the intention to act (Gibson, 1986). While these possibilities for action exist as part of the environment, their meaning is realized *only* through the individual–environment transaction. That is, from an ecological standpoint, perception is a property of an ecosystem—not of an agent. In other words,

> [t]he agent (i.e., an individual learner) is a closed (but unbounded) set of effectivities, or goal-directed functions, that identify the potential actions of the animal [individual] and that complement the affordances. The environment is a closed (but unbounded) set of affordances, or functionally defined goals, that identify the potential perceptions of the animal and that complement the effectivities. (Turvey & Shaw, 1979, p. 206)

Our goal here is to extend this perspective, providing a language for educators, who, while interested in perception, have an additional focus on supporting cognition, participation, and development, requiring the detection of, and participation in, *extended* possibilities for action (affordance networks) that are both materially and socially distributed. In our view, helping learners to participate in and even create new affordance networks is a key focus for educators.

We view the material, social, and cultural world as consisting of numerous networks that each have functional significance for in-

dividuals who hold particular goals, have particular histories, and are knowledgeably skillful (have suitable effectivity sets), or simply have the requisite scaffolding. Given our educational focus, coupled with our pragmatist ecological orientation, we have found it useful to think of the environment as consisting of functionally bound networks or what we refer to as affordance networks. *An affordance network is the collection of facts, concepts, tools, methods, practices, agendas, commitments, and even people, taken with respect to an individual, that are distributed across time and space and are viewed as necessary for the satisfaction of particular goal sets.* Nonarbitrary and even highly specific linkages constitute each network, so that the cognitive effort in coordinating the diverse entities involved is decreased (Agre & Horswill, 1997). As argued above, affordance networks, albeit functionally constrained, are culturally determined and assume a shape based on environmental, scientific, economic, or even political factors (see Latour, 1987, for examples of the making of socioscientific networks).

Affordance networks are not passive potentials simply defined by their material extension; they also have intension, in that individuals or groups intentionally create many affordance networks through which they conduct transactions. In a very real way, much of the environment that human beings interact with has been engineered in the course of cultural–historical development to capture the interests, needs, and life-worlds of people; and the human psyche has developed accordingly, leading to a correspondence of thought and external nature (Il'enkov, 1977). With that said, while an affordance network may be specified in the environment, it is available and of interest only to certain individuals who have particular goals and the requisite effectivity sets. For example, a doctor can notice particular information when examining a patient chart and can engage a network of facts, tools, resources, practices, and so on that are not available to nondoctors, with certain information relevant only to certain diagnoses. An affordance network can be focused on assessing the water quality of a stream, developing an advertisement campaign, or determining whether it is more profitable to invest in stocks or bonds; or it may involve a trajectory toward addressing the needs of a patient. While networks include concepts, facts, tools, commitments, and so on, we have found it more useful in our work to treat the total network as the "base" pedagogical unit, with the nested components being understood in terms of their function in the overall network. A key component of our argument is that understanding the network and its nested components constitutes the *minimal ontology* for supporting learning, even if the goal is that through participation in the network the learner will become attuned to some underlying invariant aspect (node) of the network (Greeno, 1998). One example is embedding a student in a rich story problem about an injured eagle that requires the student to use the Pythagorean Theorem (underlying invariant aspect) to determine the optimal solution path for reaching the eagle (Cognition and Technology Group at Vanderbilt, 1993).

Networks (and effectivity sets as presented below) are fundamentally embodied and embedded in the lived-in-world, where they take on meaning through the very relations they actualize (Barab, Hay, & Yamagata-Lynch, 2001). In other words, they are bound up in contexts of participation. As an example, a student determining the water quality of a local stream has to engage a network that draws on much information and incorporates various tools. He or she might begin with a search of what is known about the particular stream or even about water quality standards more generally. Networks exist because of the functions they serve, some being created intentionally through sociohistorical factors and some emerging more naturally because of their function in the world. For an individual, participation with a network begins with an intention (Barab, Cherkes-Julkowski, et al., 1999), for example, when the individual becomes concerned enough about the water quality of the stream to develop the intention to do something about it (e.g., Roth & Barton, 2004). Realizing this intention might involve collecting samples, determining baselines, developing hypotheses, writing reports, and even convincing stakeholders. The order in which content is presented, however, is not trivial (Barab & Landa, 1997). Clearly, the boundaries or even the direction of a "water quality inquiry" network will vary for different students and will change over time for one person. For a novice environmentalist, one's initial network does not necessarily include dissolved oxygen or turbidity; but as the network unfolds, these concepts become a part of its composition. In this way, the spatial and temporal extension of a network, from any one person's perspective, waxes and wanes depending on the particular goals, understandings, available resources, and previous experiences. One goal of schools is to expand individual networks so that they have more overlap with those engaged by experts (Lee & Roth, 2003).

What, then, determines the boundaries of a particular network? Like activity systems (e.g., Engeström, 1987), affordance networks are functionally bounded, which implies that the boundaries are dependent on the intended outcome or function that they serve (i.e., they are situated with respect to the task at hand). In our case, the boundaries of a particular network lie in those aspects of a performance necessary to functionally address a particular goal to which the network has value. Therefore, the extent to which a particular concept (e.g., sedimentation, erosion, or turbidity), fact (e.g., that dissolved oxygen levels below 7 parts per million are problematic for most streams), tool (a pH strip, kick-seine net, or computer), and participant (local ecologist, naturalist, or eighth-grade student) are part of an intentionally bounded network depends on the extent to which they are useful for satisfying an intention. Further, for a particular individual, constraints exist in social, cultural, economic, and political factors such that they mediate whether a tool, resource, or even a particular stance can be found in her network.[1]

While the nodal components clearly exist in the environment, networks are frequently engineered by people who have explicit goals for engineering them in the way they do; these goals may be scientifically based or even politically motivated. The significant point is that networks involve numerous nodes, many of which can be disentangled and applied to different networks but all of which have particular contextual links. Each node is bound up with the larger network and context through which it functions. Stripping these relations away, and teaching a particular node as a disembodied formalism, has the likely potential of being contextualized in terms of school relations. For example, learning about erosion as a fact to be memorized in school runs the risk that for the student the fact will become just that, a fact to be memorized in school. Knowing, in the ecological sense of the term, requires being able to meaningfully actualize particular affordance networks in the world.

Effectivity Sets

Gibson introduced the concept of effectivities as complementing affordances. If an affordance is a possibility for action by an individual, an effectivity is the dynamic actualization of an affordance. Functionally defined, an effectivity set constitutes those behaviors that an individual can in fact produce so as to realize and even generate affordance networks. When an individual has a particular effectivity set, he or she is more likely to perceive and interact with the world in certain ways—even noticing certain shapes of networks that are unavailable to others. This view has overlap with Foucault's (1975) notion of *gaze* or Shaffer's (2004) discussion of *epistemic frames.* For example, Foucault suggests that experts perceive the world very differently from novices and outsiders, and Shaffer suggests that an important aspect of learning is to support the learner's adoption of a new way of knowing and caring about the world. Shaffer developed "infusion activities" with the goal of helping novices adopt epistemic frames more consistent with that of experts. While we view the gaze or epistemic frame as potentially influencing which effectivity set is brought to bear in a situation, ultimately affecting the perceived affordance networks, effectivity sets are properties of individual–environment transactions out of which a new epistemic frame might emerge. That is, effectivity sets are always coupled with, and must be understood in relation to, particular affordance networks; and they always occur in the service of particular goals. From a Gibsonian perspective, being able to engage an effectivity set implies a proper *attunement* to, or *resonance* with, the nested affordances that constitute the network.

Shifting from a reductionist approach, which focuses on understanding events by explaining them as the result of the individual or the environment, an (ecological) examination of networks requires looking at individual–environment *transactions* that are spread across space and time. The notion of transaction implies that individual and environment mutually constitute each other and that the unit they constitute is the smallest meaningful entity, which cannot be further divided into smaller explanatory elements. Understanding-in-practice, a term coined by Lave, "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, 1993, pp. 51–52). Thus, for example, in an anthropological study, a scientist researching a little-known species of lizard finds herself acting in an increasingly articulated, natural, and intellectual (mathematical, conceptual) environment, which provides her with increasing numbers of sense-making resources, rather than finding herself acting in the same (i.e., stable) environment (Roth, 2004). When one adopts such a perspective, the focus is less on content acquisition and abstracted test performance and more on functional attunement and meaningful participation as one demonstrates successful engagement with a particular affordance network in terms of achieving a particular goal. Being knowledgeably skillful, in contrast to the more disembodied notion of knowing, involves being able to interact successfully with the affordance network rather than simply describing one piece (e.g., fact, concept, or tool) of the network.

In demonstrating the role of the environment in distributing cognition, Hutchins (1995) argued that navigators do not need to keep the "compass" in their mind any more than the authors of this article need to understand the programming language underlying the software employed to write the article. All that we, the authors, face is a tool useful for articulating our ideas in writing, unencumbered by attention to the technological processes that make our words and sentences appear on the monitor. Someone else has already compiled these possibilities and layered them with interfaces that make the underlying processes invisible at best; but even when they are salient, they carry with them much of what it means *to know.* In fact, the environment, from the vantage of any one individual, includes material, social, and even cultural resources, all of which *share* the act of successful participation. In contrast to traditional schema theory or constructivist-type theories with their emphasis on learner constructions, affordance networks are not read onto the world, but instead continually "transact" (are coupled) with the world as part of a perception–action cycle in which each new action potentially expands or contracts one's affordance network. Rather than separate the thinking individual from the physical environment, the ecological paradigm that underlies our thinking transcends the mind–body dualism, instead situating meaning in the dynamic transaction between mind and body. This dynamic coupling of an effectivity set to an affordance network forms what we refer to as an intentionally bound system. An intentionally bound system is not simply defined by the environment or the individual but emerges through the dynamic transaction that couples effectivity sets with affordance networks.

We have argued that a network is bounded by its function,[2] and that this function specifies which components are and are not part of the network. We have further argued that an affordance network or a particular component of an affordance network may or may not become part of particular users' life-worlds—even if it exists as part of a network system as socially agreed-upon by a professional community (e.g., the community of water ecologists). The extent to which the network, existing as part of the life-world of any one individual, differs in functionally incompatible ways from the socially agreed-upon network is the extent to which the learning process has failed to expand the learner's meaningful participation. In addition, actually *knowing* a network means understanding not only the elements of the network but also the contexts and intentions in terms of which the various elements make sense; that is, having meta-contextual awareness (appreciating the relations among content and context) of when an effectivity–affordance coupling is realizable. In this way, a network, even one absorbed into a life-world, is distributed across individuals and environments (Pea, 1993). As distributed entities, the components do not need to be kept in one's head; instead, knowing a network is a distributed, or ecological, process.

Integrating this theoretical conviction into our argument suggests that knowledge acquisition may be overrated and that a more important role of education is to stimulate meaningful participation (Sfard, 1998), or what we describe as effectivity/affordance coupling. This coupling begins with an intention; whether the intention begins with the learner or the environment is inconsequential from an ecological perspective, in that the two are simply aspects of the same phenomenon. The challenge for the teacher or any educational system is to "set the intention" and help prepare the learner such that she meaningfully engages with the network,

thereby becoming enculturated into a system through which she can participate in perception–action cycles that help to fulfill particular goals (Barab, Cherkes-Julkowski, et al., 1999). Armed with a particular intention, the learner is now able to appreciate the functional value of the content in the world—that is, for example, appreciating parts per million, the role of graphs, historical regularities, and even critical literacy as tools for making sense of the world. A point we will return to later is that an optimal learning context would not simply facilitate meaningful participation in one context, but would attune the learner to the underlying invariant structures so that she can use them as tools in other situations at other times. More problematic, however, is that learning in schools all too often focuses on the content to be learned, not on the adoption of an intention that, in order to satisfy, requires the use of the content. In the most problematic manner, schools have all too often put the metaphorical cart (the content) before the horse (those situations and reasons in which the content has value). We have now outlined our ecological characterization of knowing. Understanding the importance and challenges of arming the learner with an intention is the focus of the next section.

Life-Worlds: Individuals and Their Environments

Life-Worlds: Terms and Ideas

Theorists in disciplines as varied as phenomenology, sociology, and artificial intelligence make use of the term *life-world* in describing the individual and the material world in which the individual finds him- or herself. The term's origin lies in the concept of *umwelt,* as developed by theoretical biologists (e.g., von Uexküll, 1973/1928) and psychologists (Koffka, 1935) during the early part of the 20th century. To understand living beings, theoretical biologists distinguished between the material bodies of the animals, demarcating inner worlds, and the surrounding, material outer worlds. However, the behaviorally relevant concepts are not the inner and outer worlds, but the developmental, functionally related worlds that the organism perceives and the world that the organism affects through its actions;[3] in fact, these two worlds are not independent but co-emerge in the course of development and therefore mutually presuppose one another. Together, these two worlds constitute a functional whole (von Uexküll, 1928/1973).[4] When we use the term *functional,* we denote this relationship between organism and its life-world, which are defined in terms of one another: They are structurally coupled and therefore cannot be theorized as independent entities.

The life-world concept later found expression in the concept of affordances, created by Koffka's student and colleague James Gibson (e.g., 1986). As clarified above, an affordance is a possibility for action by an individual. Phenomenological philosophers (e.g., Merleau-Ponty, 1945), influenced by Gestalt theory, took it upon themselves to describe the phenomenal life-world, which is the specific human equivalent of the world as it is given to the individual (Lyotard, 1991) plus the social world always and already shared with others. The term life-world has now been taken up in phenomenological sociology (e.g., Schutz & Luckmann, 1973) and artificial intelligence research (e.g., Luger, 2005), where it refers to the familiar world of everyday life. Relevant to this article is the work the term does in characterizing the environment in terms of the individual (i.e., in ecological terms) without aligning to an objective view of the world or an entirely subjective one.

The life-world is the world given to the acting person in his or her perception and, therefore, the world as it makes a difference in and to his or her life; a life-world consists of those things of which the acting individual is currently conscious and the functional network that the individual engages in and enacts. A life-world is thus inherently different from the material world surrounding the person as scientists describe it and from the material aspects of one's mind. As such, "cats and people, for example, can be understood as inhabiting the same physical environment but different life-worlds. . . . Similarly, a kitchen affords a different kind of life-world to a chef than to a mechanic" (Agre & Horswill, 1997, p. 114). Accordingly, life-worlds can be partitioned along activity, spatial, material, temporal, or role lines.

> If one conceptualizes "the environment" as a monolithic whole, perhaps the way it looks when viewed from an airplane, or else the way it looks when understood through the peephole of a momentary vector of sense-perceptions, it begins to seem arbitrary, chaotic, or hostile. In a certain sense it seems static, as if it has an anatomy but no physiology. But in fact . . . the life-world has a great deal of living structure, and . . . this structure is actively maintained by agents while also providing crucial preconditions for their own cognition. (Agre & Horswill, 1997, p. 139)

However, the dynamic structure of the material world does not make itself available to all individuals in the same way; in fact, the dynamic structure is a result of the individual's prior actions in the world and, therefore, of his or her past experiences that have formed, and therefore been recorded in, the material body.

Different (physical) individuals relate to the same material environment in different ways and therefore inhabit different, personal life-worlds, which nevertheless share family resemblances across individuals. In other words, the contents of any life-world are dependent both on the individual's effectivity sets and on the available affordance networks (Roth, 2003), leading to a continuous evolution of both individual life-world and communicative patterns with others (Roth, 1999). A core goal of education is how best to support learners in developing personal life-worlds that overlap with those socially agreed-upon life-worlds that are engaged by more knowledgeable others. Similarly, a core challenge of education is how to develop curricular contexts that extend themselves meaningfully into the personal life-worlds of individuals. This is not to say that life-worlds are totally constructed by the individual person, because developmentally, others mediate the person's access to both the material and the social surroundings (Bronfenbrenner, 1979; Vygotsky, 1978) so that individual life-worlds inherently represent sociocultural and cultural–historical possibilities.

Life-worlds are always structured in patterned ways that are functionally meaningful for an individual within some *societally* defined activity and are therefore inherently intelligible to others (Leont'ev, 1981; Mikhailov, 1980). Because of our participation in specific, societally mediated and relevant activities, we are accountable for our actions to others (Bakhtin, 1993): We work to make the objects and contents of our actions intelligible to others, who, in turn, work to understand the objects and contents of our actions as intelligible. Life-worlds are therefore never created out of pure fancy but always and already show family resemblances with those of other people in our surroundings. Life-worlds, in most cases, are *intentionally bound;* that is, at some

level, that which comes to inhabit an individual's life-world does so because of its usefulness in fulfilling relevant goals and intentions. Because contexts, networks, and even objects usually have multiple affordances for the same person, they can become differentially bound up as part of one's life-world because of different intentions and prior experiences. In addition, because of differential power relationships and divisions of labor due to socioeconomic and other factors, not all possibilities are available to all people.

Overlapping Life-Worlds

We have argued that the world has dynamic order and that knowing involves an appreciation for sets of relations among contents and contexts and among individuals and environments. More precisely, we have described knowing as the process of being able to realize affordance networks; that is, the coupling of affordance networks and effectivity sets in the service of particular goals. We have also suggested that any given individual's perspective on these relations may differ greatly from those socially agreed-upon sets. Therefore, one challenge for education is to attune individuals to the structural networks that are useful for meaningful participation in the world. This process involves helping them to effectively engage, modify, and value the perception–action cycles necessary to accomplish certain goals. In other words, learning and development involve more than noticing specific possibilities for action, although such a feat is not trivial (Roth, McRobbie, Lucas, & Boutonné, 1997a). Whereas educators can mediate what and how students come to know and relate to their material and social environment—using adaptive and effective pedagogical techniques such as scaffolding or coaching to support the process of understanding—it is much more challenging to support students in developing an appreciation for, and resonance (coupling) with, socially agreed-upon networks that are distributed across time and space and are defined by a professional community. Even more challenging is to support learners in adopting a disposition to voluntarily act and an appreciation for those situations that require action.

As educators, we want to support both functioning in a particular context and participation that carries over to other places and times—not simply a short-lived or local adaptation to an immediate situation (i.e., the classroom, the next unit test). Such cross-contextual application requires that learning environments, beyond aiding students in appreciating the contextual value of that which is being learned, also serve as a mechanism for attuning the learner to the underlying invariance. This type of knowing involves not just succeeding in one situation but developing the capacity and interest to create new action possibilities, even reconstructing relations that might not have been readily apparent in the dynamic structure (Shaffer, 2004). The important point is that learning requires more than acquiring knowledge or even participating successfully in one context; it requires integrating (and potentially translating) an idea, concept, understanding, or extended network of participation as part of one's life-world so that it has functional utility in the world. In a rich learning situation, this integration involves a transactive process through which the individual, the environment, and the relations among them become fused. It is important to clarify that while we are describing learning and even development, we are doing so from an ecological perspective. Such a perspective differs from others in substantial ways:

> At the very core of an ecological orientation and distinguishing it most sharply from prevailing approaches to the study of human development is the concern with the progressive accommodation between a growing human organism and its immediate environment, and the way in which this relation is mediated by forces emanating from more remote regions in the larger physical and social milieu. (Bronfenbrenner, 1979, p. 13)

Learning in this view is an ecological, not an individualistic, phenomenon that is distributed and enables the learner to engage in progressively more adaptive individual–environment relations. In contrast to some theorists' essentially "decontextualized" organism, this view emphasizes the evolving nature and scope of children's perceived reality as it changes in their awareness and in their interactions with their physical and social environments (Barab & Plucker, 2002). It is a process of contextualized participation, and it is not coldly cognitive.

The emergence of overlapping understandings (or intentionally bound networks) is quite difficult in situations where the teacher-created context involves curricular material whose meaning is understood only if one appreciates those other contexts and systems through which it takes on authentic meaning. In fact, we have done a number of studies examining students' actual (experienced) life-worlds in comparison with those that teachers had intended. These studies show that we cannot assume students to be exposed to the same stimuli coming from an objectively given material world experienced perhaps by scientists or science teachers who already understand (Roth, McRobbie, Lucas, & Boutonné, 1997b). In addition, these studies illuminate the complex social dynamics and sociocultural and cultural–historical arrangements that support students in enlisting or failing to enlist affordance networks and appropriate effectivity sets in their life-worlds (Roth, Boutonné, McRobbie, & Lucas, 1999). We also found that conflicts and contradictions are especially accentuated when other participants in the situation *assume* they inhabit the same life-world when in fact intersubjectivity does not exist (Roth, 2000). The important point is that we need to acknowledge a potential divide between the emergent life-world as intended by the teacher and that which is experienced by individual students.

Summary of Knowing From Our Ecological Perspective

We have argued that knowledgeable participation involves engaging *affordance networks,* that is, the collection of the material, social, and human capital necessary for effective accomplishment of a particular task. Usefully engaging these networks requires that an individual have relevant effectivity sets. In clarifying the binding of effectivity sets with affordance networks we have also enlisted the notion of life-worlds, referring to the environment from the perspective of an individual. It is our conviction that unless particular components enter an individual's life-world, either intentionally or because of their being bound up in other aspects of the network that are enlisted by the individual, then they will not become part of the enacted network. Central to determining which nodes of a network get enlisted is the individual's perception of whether enacting particular affordance/effectivity couplings will be of value to adopted goals and intentions. We refer

to the coupling of an affordance network and an effectivity set, in terms of an individual life-world and in the service of a particular intention, as an *intentionally bound system.* Thus *knowing,* as described here, *is the process of successfully engaging an intentionally bound system such that particular goals can be accomplished.* In the next section we expand on the potential of a curriculum-based ecosystem for facilitating the emergence of these systems—even in school-based contexts.

Learning Environments as Curriculum-Based Ecosystems

Thus far, we have argued that knowing is a process of actualizing relations and that learning is a process of enlisting socially agreed-upon networks in one's life-world such that one can more successfully appreciate and actualize various goal paths. Scaling back from a more general ecological conceptualization of learning, in this final section we discuss an ecosystems approach with the goal of providing a useful interpretation of our perspective for teachers, curriculum developers, and instructional material authors. Three components of our framework make this a quite challenging task. First, knowing involves participation in complex networks: Any underlying invariant structure (e.g., fact, concept, principle) is simply one node of an affordance network that is bound up with various contexts-of-use; and to truly know a specific node requires an appreciation of this context-of-use. Second, the goal of schools moves beyond supporting participation in one context-of-use; instead, the expectation is that students will develop understandings that they will be able to enlist in multiple contexts-of-use. Third, we have suggested that the intended task or situation as designed by the educator may involve affordance network/effectivity set couplings very different from those already engaged in the student's life-world.

The design challenge lies in establishing contexts that support user-adopted intentions that give rise to an appreciation for, even creation of, sets of relations that are consistent with socially agreed-upon ones. From our perspective, this involves establishing rich contexts through which students attend to the socially agreed-upon formalisms and at the same time appreciate the situations for which those formalisms have value. To this end, we believe that K–12 curriculum would be more usefully arranged around problematic situations with accompanying resources and tools than around disciplinary content or particular standards. The pedagogical argument being advanced here is consistent with problem-based learning (Savery & Duffy, 1996), in which the focus is to introduce a problem that frames the learning situation and gives meaning to the content. We imagine a curriculum framed around interesting problems, where what is "interesting" and "problematic" takes place in the student–environment ecology rather than being imposed by a teacher, with students working their way through what are less like direct-instruction lesson plans and more like "curriculum-based ecosystems." The emphasis is on establishing rich contexts and then providing necessary scaffolds to support the learner in successfully enlisting meaningful trajectories through the network. Such curriculum-based ecosystems must do more than set up a rich context-of-use. To be truly valuable as educational tools, they should also attune the learner to the underlying domain formalisms that have cross-contextual value. In this way, curriculum-based ecosystems are not simply problem-based contexts but must, in addition, serve as *invariance attaining trajectories;* that is, the curriculum has the dual function of providing a rich contextual narrative to situate the content and at the same time operating as a conceptual lens into domain-specific invariant structures.

These curriculum-based ecosystems begin by setting up the problem and then making available various resources and suggested activities through which students assemble the necessary networks for solving the introduced problem. Consistent with the "anchored macrocontexts" introduced by the Cognition and Technology Group at Vanderbilt (1993) as part of their Jasper series, these curriculum-based ecosystems include the minimal framing within which certain contents are constrained and perhaps introduced; that is, each one includes the framing goal and contextual information, along with the necessary tools and resources for effectively addressing the goal. Teachers, in our vision, would have collections of curriculum-based ecosystems, categorized in part in terms of particular standards or even specific concepts that satisfaction of the task requires. This should not be taken as a move toward formalism-free contexts. As we have argued, an important challenge in any problem-based or contextually rich curriculum is to aid students in disassociating the invariant disciplinary formalisms (e.g., the notions of erosion, metaphor, and standard deviation) from the variant features of a particular context so that transfer can occur (Bransford & Schwartz, 1999; Detterman, 1993). Formalisms are useful in that they provide an important organizing role for a discipline, can mitigate contextual ambiguity about core conceptual meanings, and help reveal the common deep structure underlying different contextual phenomena, thereby potentially supporting transfer and theory building (Nathan, 2005). However, while disciplinary formalisms clearly serve a useful role for experts, our ecological framework implies that they are less useful for facilitating the conceptual development of an individual who is learning about the discipline or just beginning to recognize the value of disciplinary formalisms for meaningfully interacting with the world.

In highlighting this challenge, we offer a design framework that communicates the core tensions in building rich, curriculum-based disciplinary ecosystems (see Figure 1). This framework illuminates the challenges in balancing context and illuminating particular formalisms. In particular, we suggest that it is a balancing process in terms of the *quality of formalism* (explicit versus implicit) and the *quality of context* (noisy versus tailored). *Noisy contexts* with a lot of contextual detail and mostly implicit enlistment of formalisms can support mystery, reality, discovery, and an appreciation for the use value of formalisms. In contrast, an emphasis on *tailored contexts* with *explicit* enlistment of formalisms can prove efficient, make particular formalisms salient, and be easier to carry out in larger classrooms. However, if one focuses too much on explicit formalisms in a tailored context, the students' experience may become a school experience with a focus on memorization and grade attainment, in which case the content is less likely to become bound up in individual life-worlds. If our goal is to help students develop effectivity sets that can support meaningful realizations of affordance networks, then less formalism and a less tailored context may prove necessary. However, if there is too much context and not enough attending to the invariant property of disciplinary formalism, then students may not appreciate

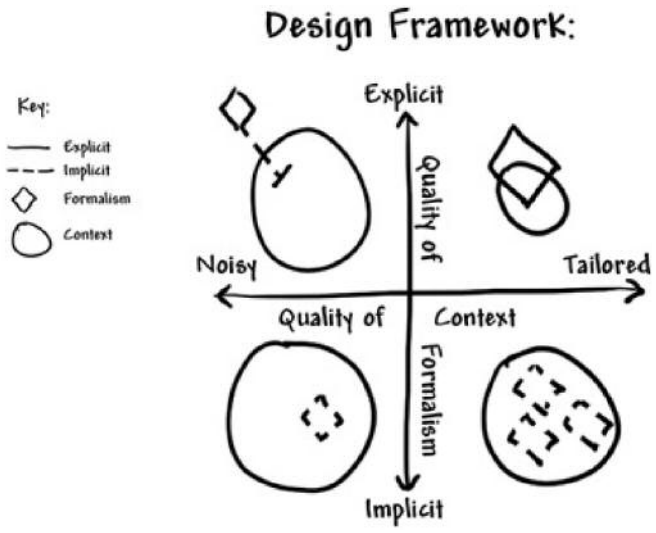

FIGURE 1. *Design framework highlighting the tension between establishing a contextually rich curricular environment and making explicit specific domain formalisms. (Figure sketched by Tyler Dodge.)*

the underlying formalism and teachers may not be able to cover enough standards within the school year.

It is for this reason that our work has focused on building rich contexts-of-use and determining which tasks will most likely facilitate students in enlisting formalisms as conceptual tools. For example, in one research project, Barab, Sadler, Heislt, Hickey, and Zuiker (2006) focused on using contextually rich simulations to support students in learning particular science standards (e.g., using evidence to warrant claims, or understanding that systems include interrelated parts) and concepts (e.g., erosion, eutrophication, hypothesis formation). Designing the curriculum involved determining in what situations these standards and concepts served as useful tools and building a relevant curricular context. A core narrative was developed in a computer program that presented a virtual park with a declining fish population, and students were tasked with clicking on virtual, nonplayer characters and engaging in dialogue in which the virtual character shares his or her perspective on the problem. Assigned the role of expert helper, students interviewed people with different perspectives on the problem (Task 1), developed an initial hypothesis about the problem (Task 2), and collected and analyzed data to develop an assertion about the problem (Task 3), with the intent of proposing a solution (Task 4). However, simply enmeshing students in such a context, even if they did adopt the intended intentions, did not guarantee that they would appreciate the underlying concepts and standards or, if they did, that they would appreciate their usefulness to other contexts-of-use or even their self-referential (formal) meanings.

Therefore, in Year 2 of our research we redesigned the curriculum, ensuring that each of the tasks involved one of the key standards and target concepts to be learned—mapping out the trajectory and aligning the various activities with the target formalisms. In this way, students' success depended on accessing embedded resources in which the formalisms were explicitly described and then using their applied interpretations of the formalisms as conceptual tools to solve problems. In addition, while situating the meaning of the core trajectory within one particular embodiment (that of the virtual park), we also developed "sideline" activities that required students to work with the underlying formalisms but through interactions in which these formalisms were situated in different or less rich contexts. The goal was to aid students in recognizing the difference between variant (contextually specific) and invariant information, the latter referring to disciplinary formalisms that have potential utility in other contexts. In the work of the Cognition and Technology Group at Vanderbilt (1993), helping students attend to the disciplinary formalisms involved multiple curricular experiences (i.e., contrasting cases) that, while taking place in different contexts, each highlighted similar nodal content (i.e., distance-rate time, Pythagorean theorem, probability).

In addition to increasing the diversity of contexts, we also decreased the number of contextual specifics so that over time students were required to understand the formalisms in increasingly tailored contexts, until the abstracted formalism itself became the focus almost explicitly. More generally, in supporting students in attending to the cross-context applicability of specific nodal content, Goldstone and Son (2005) advocated a process that they referred to as *concrete fading:* In their experiment, students first were immersed in a rich context and then worked with more abstract representations of the same underlying conceptual tools—a process that effectively facilitated transfer. This is similar to the work of Hickey and Zuiker (2003), who had students take formative quizzes that focused their attention on the invariant aspects of the curriculum, providing them with formative feedback to stimulate interrogations of the underlying formalisms in collaboration with peers. When using contextually rich problems, we have found that, in addition to contrasting cases, some type of meta-contextual decomposition in which learners interrogate the problem in terms of the invariant and variant aspects is an important step in fostering the development of a cross-contextual appreciation for the underlying invariant structures.

Still, it is one thing to appreciate the existence of such networks and another to care to engage them, and still another to be committed to creating new networks to achieve personal goals that may not have been required by the teacher or even directly salient in the environment. In our work, this has meant the design of learning contexts that wrap themselves up in and help to define student lifeworlds. For example, in Barab's Quest Atlantis project, an educational multi-user virtual environment for schoolchildren aged 11–13 years, the focus is not on supporting fact, concept, or skill attainment but rather on aiding students in the appropriation and valuing of "life commitments" (e.g., environmental awareness, social responsibility, creative expression) that involve networks of participation (Barab, Thomas, Dodge, Carteaux, & Tuzun, 2005). These networks are intentionally designed to be personally engaging yet enlist educationally meaningful practices in a way that, over time, collectively comes to represent and inspire an evolving identity related to one's involvement with the particular life commitment (Barab, Thomas, Dodge, Squire, & Newell, 2004). In one case a 10-year-old girl who became committed to environmental awareness ended up working on more than a dozen activities spanning more than 3 months that were all connected to that commitment. The resultant "understandings" in such ex-

tended trajectories represent not simple acquisitions but relations among learners and affordance networks that include constellations of people, facts, concepts, ideas, and tools. The important point is that eventually the teacher needs to stop governing the invariance–variance relations and the learner's relations to these, and the learner needs to create her own contexts-of-use.

Summary

We have argued that learning is not simply scoring high on a test or assignment, but should involve increasing possibilities for action in the world. Learning and participation, with respect to this project and our ecological framework, is about successfully participating as part of an ecosystem, an intentionally bound network, and it fundamentally involves increasing possibilities for action in the world. Life-world expansion, as the ultimate trajectory of learning, involves engaging in sets of experiences that have overlapping core components such that children build up "effectivity sets" that span multiple affordance networks—potentially evolving into new ways of interacting with the world. Transfer can occur when individuals begin to see different contexts as having similar underlying affordance structures—even in the context of differing contextual particulars. In the best cases, individuals appreciate the power of, or adopt commitments with respect to, a particular effectivity set and begin to assert this "toolset" in multiple situations even when the affordances are not readily apparent on the surface.

Education, however, represents even more than the simple appropriation of or participation in intentionally bound networks, although such an emphasis would be a meaningful extension to the test-driven and fact-acquisition agenda that many policymakers and administrators currently support. Even beyond the shift from facts or concepts to meaningful participation in affordance networks, education should stimulate an appreciation for, and desire to be part of, contexts through which these networks take on meaning, as well as equipping students so that they can create new and useful affordance networks. Such a system involves inspiring life trajectories, not simply curricular trajectories, that bind themselves up with student passions. The depressing reality, especially when it comes to forming children's identities, is that the sources of the most compelling networks that capture the life-worlds of children are not educators in the traditional sense but multinational corporations whose primary interest is in appeasing shareholders, not necessarily preparing good citizens (Hersch, 1998; Herz, 1997). Educators need to better understand the types of curriculum that will engage children while also supporting disciplinary learning and future-oriented trajectories. At a minimum, we have argued, this requires building curriculum-based ecosystems that include rich contextual specifics and, at the same time, engage the learner in invariance attunement trajectories so that understandings are not contextually isolated to the contexts in which they were learned.

It is for this reason that educators and parents must take an increased interest in what types of contexts and goals are likely to engage children's life-worlds. Facilitating participation that binds itself into both the life-world of the individual and the significant affordance networks of the environment is not a simple matter—but it is, we believe, a necessary one if schools are to support meaningful learning. While educators cannot modify the curriculum for each student, they can design contexts that are more likely to engage a diverse range of students because of their richness and underlying narratives, rather than because of some disciplinary formalism that all students are mandated to know about. It is beyond the scope of this article (and may not be possible at all) to advance a set of prescriptive principles that others can use to accomplish this task; however, we have provided an ecological focal point for curriculum design and highlighted some of the key tensions that need to be balanced if one adopts such a perspective. At its core, our pedagogical argument highlights the primacy of rich experience and the importance of enmeshing students in such experience—not simply describing abstracted *contents.* Our goal in this article was to advance an ecological characterization of knowing, to illuminate the challenges of supporting students in knowing in this way, and to outline, if only in broad strokes, a means for educators to support this process.

NOTES

[1]As is well known to sociocultural theorists, when characterizing any activity one must consider the transactions among the individual, available tools, division of labor, norms and rules, sociocultural history, object of focus, and goals of the learner. While the idea that in characterizing an activity one needs to describe goals, available tools, division of labor, and operating norms and rules has overlap with discussions of activity theory (Engeström, 1987), we believe that the frame of affordance networks more directly acknowledges the structured world and the unfolding shape of these networks than do activity-theoretic accounts. Further, that frame also leaves room for our conviction that networks are dynamic and even intentional, such that a particular network is as likely to enlist a person's life-world as the person is likely to enlist the network.

[2]In using the word "function," we are drawing on the tradition of pragmatism as communicated by Dewey, Peirce, and James. From a pragmatist perspective, truth lies not in an abstract characterization but in the practical consequences as they unfold through the experience of life.

[3]In German, the two worlds were called *Merkwelt,* literally the "notice-world," and *Wirkwelt,* literally the "effect-world" (von Uexküll, 1928/1973).

[4]The term *umwelt* is widely used in the Anglo-Saxon semiotics literature for describing a variety of organism–environment interactions—including the interactions of plants, animals, and human beings with their settings (Deely, 2001). The functional relations of these mutually presupposing worlds have been termed *Funktionskreis* (functional circle; von Uexküll, 1928/1973) or *Gestaltkreis* (Gestalt circle; von Weizsäcker, 1973/1940). Leont'ev's (1978) concept of the *object* integrates and dialectically opposes (a) the world as it appears to and is acted upon by the individual, and (b) the material world.

REFERENCES

Agre, P. E., & Horswill, I. (1997). Life–world analysis. *Journal of Artificial Intelligence Research, 6,* 111–145.

Bakhtin, M. M. (1993). *Toward a philosophy of the act.* Austin: University of Texas Press.

Barab, S. A., Cherkes-Julkowski, M., Swenson, R., Garrett, S., Shaw, R. E., & Young, M. (1999). Principles of self-organization: Ecologizing the learner–facilitator system. *Journal of the Learning Sciences, 8,* 349–390.

Barab, S. A., Hay, K. E., & Yamagata-Lynch, L. C. (2001). Constructing networks of activity: An in-situ research methodology. *Journal of the Learning Sciences, 10,* 63–112.

Barab, S. A., & Landa, A. (1997). Designing effective interdisciplinary anchors. *Educational Leadership, 54*(6), 52–55.

Barab, S. A., & Plucker, J. A. (2002). Smart people or smart contexts? Cognition, ability, and talent development in an age of situated approaches to knowing and learning. *Educational Psychologist, 37,* 165–182.

Barab, S., Sadler, T., Heislt, C., Hickey, D., & Zuiker, S. (2006, April). *Relating narrative, inquiry, and inscriptions: A framework for socio-scientific inquiry.* Paper presented at the annual meeting of the American Educational Research Association, San Francisco.

Barab, S. A., Thomas, M., Dodge, T., Carteaux, R., & Tuzun, H. (2005). Making learning fun: Quest Atlantis, a game without guns. *Educational Technology Research and Development, 5*(1), 86–108.

Barab, S. A., Thomas, M. K., Dodge, T., Squire, K., & Newell, M. (2004). Critical design ethnography: Designing for change. *Anthropology & Education Quarterly, 35,* 254–268.

Bertalanffy, L. (1952). *Problems of life.* London: Watts.

Bransford, J. D., Brown, A. L., & Cocking, R. R. (Eds.). (2002). *How people learn: Brain, mind, experience, and school.* Washington, DC: National Academy Press.

Bransford, J. D., & Schwartz, D. (1999). Rethinking transfer: A simple proposal with multiple implications. In A. Iran-Nejad & P. D. Pearson (Eds.), *Review of Research in Education* (Vol. 24, pp. 61–100). Washington, DC: American Educational Research Association.

Bronfenbrenner, U. (1979). *The ecology of human development.* Cambridge, MA: Harvard University Press.

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher, 18*(1), 32–42.

Cognition and Technology Group at Vanderbilt. (1993). Anchored instruction and situated cognition revisited. *Educational Technology, 33*(3), 52–70.

Deely, J. (2001). Umwelt. *Semiotica, 134,* 125–135.

Detterman, D. R. (1993). The case for prosecution: Transfer as an epiphenomenon. In D. K. Detterman & R. J. Sternberg (Eds.), *Transfer on trial: Intelligence, cognition, and instruction* (pp. 1–24). Norwood, NJ: Ablex.

Engeström, Y. (1987). *Learning by expanding.* Helsinki, Finland: Orienta-Konsultit.

Engeström, Y., Engeström, R., & Vähäaho, T. (1999). When the center does not hold: The importance of knotworking. In S. Chaiklin, M. Hedegaard, & U. J. Jensen (Eds.), *Activity theory and social practice* (pp. 345–374). Aarhus, Denmark: Aarhus University Press.

Foucault, M. (1975). *The birth of the clinic: An archeology of medical perception.* New York: Vintage.

Gibson, J. J. (1986). *The ecological approach to visual perception.* Hillsdale, NJ: Lawrence Erlbaum.

Goldstone, R. L., & Son, J. Y. (2005). The transfer of scientific principles using concrete and idealized simulations. *Journal of the Learning Sciences, 14,* 69–110.

Greeno, J. G. (1998). The situativity of knowing, learning, and research. *American Psychologist, 53,* 5–17.

Greeno, J. G., & Moore, J. L. (1993). Situativity and symbols: Response to Vera and Simon. *Cognitive Science, 17,* 49–61.

Heidegger, M. (1996). *Being and time* (J. Stambaugh, Trans.). Albany: State University of New York Press.

Hersch, P. (1998). *A tribe apart: A journey into the heart of American adolescence.* New York: Fawcett Columbine.

Herz, J. C. (1997). *Joystick nation: How videogames ate our quarters, won our hearts, and rewired our minds.* Boston: Little, Brown.

Hickey, D. T., & Zuiker, S. J. (2003). A new perspective for evaluation of innovative science environments. *Science Education, 87*(3), 539–563.

Hoffmann, M. H. G., & Roth, W.-M. (2005). What you should know to survive in knowledge societies: On a semiotic understanding of "knowledge." *Semiotica, 156,* 101–138.

Hutchins, E. (1995). *Cognition in the wild.* Cambridge, MA: MIT Press.

Il'enkov, E. (1977). *Dialectical logic: Essays in its history and theory* (H. Campbell Creighton, Trans.). Moscow: Progress.

Koffka, K. (1935). *Principles of Gestalt psychology.* New York: Harcourt.

Latour, B. (1987). *Science in action: How to follow scientists and engineers through society.* Milton Keynes, UK: Open University Press.

Lave, J. (1988). *Cognition in practice: Mind, mathematics and culture in everyday life.* Cambridge, UK: Cambridge University Press.

Lave, J. (1993). Introduction. In J. Lave & S. Chaiklin (Eds.), *Understanding practice: Perspectives on activity and context* (pp. 3–34). New York: Cambridge University Press.

Lave, J., Murtaugh, M., & de la Rocha, O. (1984). The dialectic of arithmetic in grocery shopping. In B. Rogoff & J. Lave (Eds.), *Everyday cognition: Its development in social context* (pp. 67–94). Cambridge, MA: Harvard University Press.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation.* New York: Cambridge University Press.

Lee, S. H., & Roth, W.-M. (2003). Science and the "good citizen": Community based scientific literacy. *Science, Technology, & Human Values, 28,* 403–424.

Lemke, J. (1997). Cognition, context, and learning: A social semiotic perspective. In D. Kirshner & J. A. Whitson (Eds.), *Situated cognition: Social, semiotic, and psychological perspectives* (pp. 37–56). Mahwah, NJ: Lawrence Erlbaum.

Leont'ev, A. N. (1978). *Activity, consciousness and personality.* Englewood Cliffs, NJ: Prentice Hall.

Leont'ev, A. N. (1981). *Problems of the development of mind.* Moscow: Progress.

Luger, G. F. (2005). *Artificial intelligence: Structures and strategies for complex problem solving* (5th ed.). London: Addison-Wesley.

Lyotard, J.-F. (1991). *Phenomenology.* Albany: State University of New York Press.

Merleau-Ponty, M. (1945). *Phénoménologie de la perception* [Phenomenology of perception]. Paris: Gallimard.

Mikhailov, F. (1980). *The riddle of self.* Moscow: Progress.

Nathan, M. J. (2005). *Rethinking formalisms in formal education* (WCER Working Paper Series No. 2005-11). Madison: Wisconsin Center for Educational Research.

Pea, R. D. (1993). Practices of distributed intelligence and designs for education. In G. Salomon (Ed.), *Distributed cognitions: Psychological and educational considerations* (pp. 47–87). New York: Cambridge University Press.

Prigogine, I., & Stengers, I. (1984). *Order out of chaos: Man's dialogue with nature.* New York: Bantam.

Roth, W.-M. (1999). The evolution of *umwelt* and communication. *Cybernetics & Human Knowing, 6*(4), 5–23.

Roth, W.-M. (2000). Learning environments research, life-world analysis, and solidarity in practice. *Learning Environments Research, 2,* 225–247.

Roth, W.-M. (2003). From environmental determination to cultural–historical mediation: Toward biologically plausible social theories. *Cybernetics & Human Knowing, 10*(2), 8–28.

Roth, W.-M. (2004). Emergence of graphing practices in scientific research. *Journal of Cognition and Culture, 4,* 595–627.

Roth, W.-M., & Barton, A. C. (2004). *Rethinking scientific literacy.* New York: Routledge.

Roth, W.-M., Boutonné, S., McRobbie, C., & Lucas, K. B. (1999). One class, many worlds. *International Journal of Science Education, 21,* 59–75.

Roth, W.-M., & McGinn, M. K. (1998). >unDELETE science education: /lives/work/voices. *Journal of Research in Science Teaching, 35,* 399–421.

Roth, W.-M., & McRobbie, C. (1999). Life-worlds and the "w/ri(gh)ting" of classroom research. *Journal of Curriculum Studies, 31,* 501–522.

Roth, W.-M., McRobbie, C., Lucas, K. B., & Boutonné, S. (1997a). The local production of order in traditional science laboratories: A phenomenological analysis. *Learning and Instruction, 7,* 107–136.

Roth, W.-M., McRobbie, C., Lucas, K. B., & Boutonné, S. (1997b). Why do students fail to learn from demonstrations? A social practice perspective on learning in physics. *Journal of Research in Science Teaching, 34,* 509–533.

Savery, J., & Duffy, T. (1996). Problem based learning: An instructional model and its constructivist framework. In B. Wilson (Ed.), *Constructivist learning environments: Case studies in instructional design* (pp. 135–148). Englewood Cliffs, NJ: Educational Technology Publications.

Schutz, A., & Luckmann, T. (1973). *The structures of the life-world.* Evanston, IL: Northwestern University Press.

Sfard, A. (1998). On two metaphors for learning and the dangers of choosing just one. *Educational Researcher, 27*(2), 4–13.

Shaffer, D. W. (2004). Pedagogical praxis: The professions as models for post-industrial education. *Teachers College Record, 106*(7), 1401–1421.

Shaw, R. E., & Turvey, M. T. (1981). Coalitions as models for ecosystems: A realistic perspective on perceptual organization. In M. Kubovy & J. R. Pomerantz (Eds.), *Perceptual organization* (pp. 343–408). Hillsdale, NJ: Lawrence Erlbaum.

Swenson, R. (1989). Emergent attractors and the law of maximum entropy production. *Systems Research, 6,* 187–197.

Swenson, R. (1999). Epistemic ordering and the development of space–time: Intentionality as a universal entailment. *Semiotica, 126*(1), 1–31.

Tobin, K., & Roth, W.-M. (2006). *Teaching to learn: A view from the field.* Rotterdam: SensePublishers.

Turvey, M. T., & Shaw, R. E. (1979). The primacy of perceiving: An ecological reformulation of perception for understanding memory. In L. G. Nilsson (Ed.), *Perspectives on memory research* (pp. 167–222). Hillsdale, NJ: Lawrence Erlbaum.

von Uexküll, J. (1973). *Theoretische Biologie* [Theoretical biology]. Frankfurt: Suhrkamp. (Original work published in 1928)

von Weizsäcker, V. (1973). *Der Gestaltkreis* [The Gestalt circle]. Frankfurt: Suhrkamp. (Original work published in 1940)

Vygotsky, L. (1978). *Mind in society: The development of higher psychological processes.* Cambridge, MA: Harvard University Press.

Walkerdine, V. (1997). Redefining the subject in situated cognition theory. In D. Kirshner & J. A. Whitson (Eds.), *Situated cognition: Social, semiotic, and psychological perspectives* (pp. 57–70). Mahwah, NJ: Lawrence Erlbaum.

Wenger, E. (1998). *Communities of practice: Learning, meaning, and identity.* Cambridge, UK: Cambridge University Press.

Whitehead, A. N. (1929). *The aims of education and other essays.* New York: MacMillan.

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