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LEARNING IS SCAFFOLDED CONSTRUCTION

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Standard models of representation as encodings of what is represented yield models of knowledge as banks of such encodings. Learning, in such a view, is the transmission of new encodings into those storage banks in the mind. Technology, therefore, can be a wonderful aid in enhancing the accessibility and transmission of these encoded representations—in enhancing learning as viewed in this model. Every component and every step of this framework, however, is false, beginning with the central presuppositions about the nature of representation. This chapter outlines the fatal critiques of standard encoding models, introduces an alternative model of representation that solves and dissolves these aporia, and shows that this alternative model of representation forces a model of learning as construction, and a functional model of scaffolding that puts scaffolding, self-scaffolding, and the scaffolding of self-scaffolding at the center of educational aims. This framework places technology at the center of an agentive and social process that participates in and nurtures such scaffolding, rather than just a high bandwidth storage and retrieval device.

Education serves the purpose of nurturing and guiding learning and development. As such, its design and its practice necessarily involve presuppositions about the nature of learning and development—about the nature of human epistemology. Conversely, such epistemological assumptions inform and constrain, sometimes tightly inform and constrain, educational theory and practice.

THE MIND AS WAX

Aristotle likened perception to the impression a signet ring can impress into wax. Aristotle's model of mind and epistemology was richer than this, but empiricisms, including contemporary empiricist epistemologies, are pretty much restricted to contemporary, technologically updated, versions of perceptual impressions into wax minds.

Transduction into the Wax

Unfortunately, the contemporary technological updates on such notions provide no improvement with respect to the basic epistemological issues involved. No one takes rings pressing into wax seriously today, but light being transduced in the retina into sensory encodings (e.g., Carlson, 2000; Fodor and Pylyshyn, 1981), and learning as induction (a scratching into the wax over time rather than an immediate impression), provide no more of a model of how the mind can come to know anything about its world than does the wax metaphor. Strictly, "transduction" is a change in form of energy, and that certainly occurs when light strikes the retina, but such a physical, factual process of energy transformation provides no clue about how such a process either constitutes or feeds into a normative representation—a representation that could be true or false—of that light or of the world from which it has been reflected. "Transduction" (or induction) sounds better to contemporary ears, but it makes no progress at all in the task of understanding epistemology (Bickhard and Richie, 1983; Bickhard, 2003/2004):

> "A theory of encoding is, therefore, what we need to complete the bridge between . . . semantics and the computational story about thinking. . . . [An account of] encoding [is] pie in the sky so far. . . .we haven't got a ghost of a Naturalistic theory about [encoding]." (Fodor, 1987, p. 81)
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> "But of the semanticity of mental representations we have, as things now stand, no adequate account." (Fodor, 1990, p. 28)
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> "The right questions are: 'How do mental representations represent?' and 'How are we to reconcile atomism about the individuation of concepts with the holism of such key cognitive processes as inductive inference and the fixation of belief?' Pretty much all we know about the first question is that here Hume was, for once, wrong: mental representation doesn't reduce to mental imaging." (Fodor, 1994, p. 113)
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> "Hume hasn't, in short, the slightest idea how 'the world' or 'the object' (or anything else) *could* cause an impression (and neither, of course, do we)." (Fodor, 2003, p. 121, footnote 10)

Nevertheless, despite over two millennia of failures to make good on such notions, general empiricist approaches to epistemology dominate contemporary thought, especially in psychology and education. I will argue that these approaches are fundamentally in error, and are seriously misleading with respect to educational issues.

RATIONALISM?

One reason for the continued prevalence of empiricist epistemologies is that their primary alternatives have been various versions of rationalism, with its contemporary version of innatism. These positions are tightly interconnected. They are all versions of foundationalism: the assumption that all representation must be constructed out of foundational representations. Within such a foundationalism, the primary question is where the basic representations, the representational atoms out of which everything else is constructed, come from, and the answer would seem to have to be either the environment—empiricism—or the mind or genes—rationalism and innatism. Struggles between these two positions have permeated the historical scene, but neither one can ultimately be correct: neither one has any account of how representation could emerge out of nonrepresentational phenomena.

We know that representation did *not* exist on earth four or five billion years ago, and did not exist *anywhere* at the point of the Big Bang, and that representation *does* exist now, so it *has* to have emerged, to have come into being out of nonrepresentational phenomena. Any position that makes such emergence impossible is, thus, refuted. Therefore, both empiricism and rationalism are refuted: anything that requires that X already exist in order to explain X cannot be correct. It is circular as a model of the nature and origin of X, for any X whatsoever, including, in particular, representation.

From Empiricism to Rationalism

One route from empiricism to rationalism, in fact, is to note that sensory transduction does nothing to provide or constitute representational *content* about the sensory inputs—where content is the internal specification of what is supposed to be being represented. That is, the neural end of an energy transduction does not provide any content about there ever having been a transduction, what the transduction was from, what sources the energy that was transduced might have come from, etc. The neural end of an energy transduction is a factual neural process that does not in itself constitute anything normative, and certainly not normatively representational. It is a factual neural process and does not constitute or provide the representational normativity of truth or falsity. It does not in itself provide the necessary representational foundations.

If such transductions are to be taken as the ground of representation, then, the contents involved must come from somewhere else. They do not come into the nervous system with the sensory input energy per se. And the "obvious" alternative is that the contents are already there—they are inherent in the mind or in the genes: rationalism or innatism.

Rationalism as Innatism

The innatist version of rationalism does assume that representation has emerged: it has emerged in evolutionary processes. But there is no model given of how that could have occurred, nor any argument offered of how evolution could accomplish such emergence, but learning and development not be able to accomplish it. Contemporary innatism is simply a pushing of the problem of representational emergence off onto evolution as a means of avoiding the issue (Bickhard, 2003/2004; Fodor, 1981). It is not a solution, and does not offer any guidance toward a solution.

Corollaries

Empiricist assumptions and presuppositions generate a large and complex labyrinth of derivative problems. Many of these have been discovered over the centuries, and major efforts expended on attempting to solve them. Of course, if the basic approach is in error, such efforts are doomed. Nevertheless, they continue today.

Such assumptions also generate multiple corollaries, correlative properties of representation and cognition that follow from the empiricist foundations. Interestingly, it is possible, and has occurred historically numerous times, that one or more of these corollaries has been taken to be a stance from which to criticize and attempt to correct other positions within the overall empiricist or foundationalist forest: It has been difficult to get an overall view.

Empiricist corollaries often influence conceptions of learning and development, and, therefore, education, without any recognition that they are related to empiricism at all. They can serve as background assumptions, so taken for granted that they scarcely come into view.

Three such interrelated corollaries are:

1. The mind is a passive receiver of input and knowledge,
2. Learning is independent of prior state and of context,
3. The ideal form of learning is errorless learning.

The mind is passive in both the wax and the transduction (and induction) scenarios. Agents may interact with their environments, but such action and interaction is at best indirectly relevant to the nature and acquisition of information. Such passivity of mind (and brain!) is inherent in contemporary computationalist, connectionist, and information processing approaches to cognition. Action occurs, but it is guided by and follows from representation; it is irrelevant to the nature of representation.

Correlatively, those impressions, transductions, and inductions occur into a passive mind independently of what else might already be present in that mind or present in the environment. Information is transduced or induced one signet ring, one fact, at a time.

Also correlatively, the best learning is by a single clear impression—no error. Errors are constituted in unclear or false inductions, and, although inevitable, simply require cleaning up and elimination. They serve no function.

PROBLEMS WITH ENCODINGISM

In spite of their longevity and dominance, assumptions that representation is constituted as encoding, and, therefore, that learning is constituted as transduction and induction, are incorrect, and not just incorrect, they are foundationally, fatally, in error.

One perspective on this point derives from considering the properties of genuine encodings. Encodings do exist; the problems stem from assumptions that all representation is constituted as encodings. I will argue that genuine encodings must be a derivative form of representation, and cannot be foundational.

Consider the encoding of "S" into ". . ." in Morse code. This is useful because ". . ." can be sent over telegraph wires while "S" cannot. But, crucially, ". . ." obtains its representational content, its specification of what it is supposed to represent, by being understood as a stand-in for "S." It derives its status as a representation by borrowing its content from "S." And that status requires that someone already represent "S," already represent ". . ." and already represent the (stand-in) relationship between them. Encodings must have some representational content in order to be representations at all, and if encodings must borrow their representational contents from other representations, then they cannot be the foundational form of representation. As presumed foundations, encodings would have nothing to borrow their contents from, and, therefore, could not be encodings or representations at all.

If the conventionality of Morse code is distracting, consider the sense in which the neutrino count in a physics experiment encodes certain properties of fusion processes in the sun. Here there is no question of the relationship being conventional, but it is still the case that the encoding relationship is constituted in the physicists' understandings, representations, of the neutrino count, the fusion processes, and their relationships. Without that prior frame of representations to provide representational content, there might be a factual or causal relationship, but there would be no representational relationship.

In an important sense, this point is just a different perspective on the fact that encodings cannot account for the emergence of representational content. Encodings must borrow content, because they cannot emergently generate it.

Encodings are simply changes in form of representation, via represented relationships among representations that support such content borrowing from one form to another. If we assume or presuppose that encodings could always borrow content from themselves, we enter into a circularity or infinite regress.

Another perspective on these problems is provided in Piaget's copy argument (Piaget, 1970). Piaget argued that our representations of the world could not be constituted as copies of that world, because we would have to already know how the world was in order to be able to construct our copies of it. That is, we have to already know about the light in order for the transductions into neural activity to be able to provide representations of that light, or of the world in order to construct our representations of the world from which the light has been reflected. Any such account is circular.

Another perspective on this circularity is obtained by considering the sort of relationships that might be thought to support encoding relationships between neural activities and the world. There are a number of variations on this theme, but they all encounter similar problems. Some propose that the crucial encoding relationship—the representation constituting correspondence—is a causal relationship between brain activities and what the light has reflected from, others that it is most crucially a lawful relationship, perhaps a causal law, and others that it is an informational relationship, where to be in an informational relationship with something is taken to be constituted in being correlated with that something, of covarying with it.

Consider now the light reflected from a table into a retina, being transduced, and evoking ensuing activity in the brain. We would like to be able to say that there is a representation of the table. But if we consider any of the presumed possible supporting correspondences, we find a plethora of instances, spread throughout both space and time. Every instance of every causal interaction in the universe is causal, lawful, and informational: which of them are representational? Further, to be in a causal or lawful or informational relationship with the table is also to be in such a relationship with the light in front of the retina, with the quantum activities in the surface of the table, with the table a minute ago (instead of a few nanoseconds ago when *this* light reflected from it), with the table last year, with the forming of the materials out of which the table is constructed, etc. etc. all the way back to the Big Bang. Which of all of these relationships is the representational one? And how does the person "know" which is the right one? And note, that any answer to the question of how the agent knows what the right relationship is *with* presupposes that the agent *already has* representational content for that "right" other end of the encoding relationship. We have encountered the circularity again.

Ignore for a moment these problems of which correspondence is supposed to be the right representational one, and consider yet another problem. Whatever the special correspondence is supposed to be, it either exists or it does not. There are no further possibilities. If it exists, then, by assumption, the representation exists, *and it is correct*. If it does not exist, then the representation does not exist. There are no further possibilities. But there is a further possibility that has to be modeled: the representation exists but it is incorrect. Yet there is no third possibility within the encoding correspondence framework for attempting to model the possibility of incorrect representation. These models have grave difficulty, at best, in accounting for the possibility of representational error (Cummins, 1996; Dretske, 1988; Fodor, 1987b, 1990b; Millikan, 1984, 1993).

There are myriad multifarious problems with such models of representation (Bickhard and Terveen, 1995; Bickhard, 2003/2004), but it should by now be clear that they have serious problems, likely fatal problems. These should be taken as refutations, even reductios, but what is the alternative? It would seem to make sense to ask: "What else is there besides encodings?"

That is, these should be taken to not only refute the encoding models of representation, but also the corollaries and presumed guidance from those corollaries for learning, development, and education—but what is the alternative, and what guidances would it provide?

INTERACTION AND REPRESENTATION

Consider an animal needing to make a selection of what further action or interaction to engage in. We might take for an example a frog that could flick its tongue one way with the possibility of thereby eating a fly, or another way with the possibility of thereby eating a different fly, or yet another way with the possibility of eating a worm, or, finally, it could jump in the water and thereby avoid the hawk whose shadow just passed by.

There are many functions that need to be served in order for the frog to be able to make such a selection, such as being able to assess these various possibilities with respect to importance and goals, but my focus at this point will be on the fact that the frog must have some indication of what those interaction possibilities are in order for any such selection process to have some possibilities to select among. Such indications of interaction possibilities, I will claim, constitute the emergence of a primitive form of representation.

Truth Value

In particular, such indications of interactive potentiality have truth value. They can be true or false; the indicated possibilities can exist or not exist. The indications constitute implicit predications of the environment—this environment is one that will support this indicated kind of interaction—and those predications can be true or false.

Note that there is no difficulty here in accounting for the possibility of representational error. If the indication exists, then the representation exists; if the indication does not exist, then the representation does not exist. Further, if the indication, thus the representation, exists, it could be true or it could be false. It depends on whether or not the current environment is in fact one that would support the indicated kind of interaction.

Still further, if the indicated interaction is engaged in by the agent, that interaction might proceed as indicated or it might not. If it does not, the internal processes in the organism will not proceed within the bounds of what has been indicated, and the organism can, in principle, if the species and the animal are complex enough, detect that the predication was false. This model not only accounts for the possibility of representational error, it also accounts for the possibility of system or organism detectable representational error.

This point is important. There has been a minor industry in the philosophical literature attempting to account for representational error (Cummins, 1996; Dretske, 1988; Fodor, 1987b, 1990b; Millikan, 1984, 1993), but, even if they were to be accepted as solving this problem, not a single one of these models attempts to account for system detectable representational error. Yet without system detectable representational error, error guided behavior and error guided learning would not be possible. It is clear that error guided behavior and error guided learning occur, so, once again, encodingism models are refuted.

Furthermore, insofar as encodingist models cannot account for organism detectable representational error, they also cannot provide any guidance concerning the function that error serves in learning and development, and, consequently, concerning educational design and practice. The reason that indications of interactive potentiality can model these phenomena is that such indications are, in effect, anticipatory into the future, and modal, about potentialities. Those future potentialities can exist or not, whether or not they are indicated, and their falsity can be detected if they are engaged, thereby tested, and the interaction fails to proceed as anticipated. Encoding models, in contrast, are not future oriented, but backward oriented, into the past, attempting to look back down the input stream. As Dewey characterized them, they are spectator models, not agent models (Smith, 1987; Tiles, 1990).

Content

An indication of interactive potentiality may be true or false as an implicit predication about the environment, but what is its content? Some environments, with favorable properties, would support the indicated potentiality, while other environments, with other properties, would not. The relationship between an indication of interaction potentiality and the environments and properties that would support that indication is an intrinsic one: indications of particular interaction potentialities *necessarily* presuppose that the crucial properties hold of *this* environment (Bickhard, 2003). In that sense, the predication is a predication that this environment is one of those that does have the crucial supportive properties. It is the possession of those properties that is being predicated of the environment. Those properties, or that class of favorable environments, constitute the content of the representation. It is the implicit predication of those properties *about* the environment that is true or false. This is the basic form of intentionality.

Note however that those properties are nowhere explicit in a simple indication of interaction potentiality. They are presupposed, implicit, not explicit or encoded. This implicitness of content is quite different from standard encoding models: encodings must have understood, therefore explicit, content in order to be representations at all. The implicitness of interactive presuppositions is one of the powers of the interactive model, providing, for example, a resolution of the frame problems (Bickhard, 2001; Bickhard and Terveen, 1995).

This, of course, issues a promissory note to be able to account for explicit representation, along with multiple other notes and responses to potential challenges. The challenge that I would like to address here, however, is that of the representations of objects. It might seem that such an interactive model could handle representations of interactive potentialities, but what about more familiar kinds of representations, such as of objects?

Object Representations

To address this, I need to elaborate a little further some of the resources available in the model. First, note that the frog can have multiple interaction potentialities indicated about a single environment: e.g., differing fly and worm eating opportunities. Indications of interactive potentiality can branch into more than one interactive "direction."

Second, note that the relationships in the frog between a particular kind of visual scan and the setting up of an indication of the possibility of a certain kind of tongue flicking and eating is a conditional functional relationship in that frog even if the visual scan condition has not been met at this moment. That is, the frog is ready to set up tongue flicking and eating indications *if* certain kinds of visual scans occur, and this is so ongoingly, even when no visual scan of that kind has occurred. So, indications of interactive potentiality are conditional, conditional on prior interactions and their outcomes.

Given that they are conditional, in sufficiently complex organisms those conditional indications could iterate, with one interaction setting up the conditions under which a next (or several "nexts") would then be possible. I might be able to open my refrigerator to get a drink, but I have to go to the kitchen first. Interaction potentialities, then, can branch and they can iterate. They can form possibly complex, possibly *very* complex, webs of conditionalized interaction potentialities. This is the basic resource need to account for object representations.

Consider now a child's toy block. The child can engage in multiple visual scans of various sides and aspects of the block, he or she can manipulate it, chew on it, drop it, throw it, and so on. Furthermore, the availability of any one of these indicates the potentiality of all the others, perhaps with intermediate interaction, such as manipulating the block in order to bring a particular visual aspect into view. The set of these interactive potentialities are all mutually reachable from each other.

Further, this internally mutually reachable organization of interaction potentialities remains invariant under a large class of other possibilities. The block's interactive potentialities remain if the child leaves it on the floor and leaves the room, puts it in the toy box, throws it far away, etc., again perhaps with particular intermediate interactions to bring the block into direct interactive range. This invariance, however, does not hold with respect to all possible events and interactions. If the block is crushed or burned, the pattern of interaction possibilities is destroyed.

Such invariant internally reachable organizations of interactive potentialities constitute basic representations of simple manipulable objects. This is what the object is in the most primitive sense—before any stories about atoms or molecules or earth, air, fire, and water, or other adult metaphysics are learned.

Pragmatism

In this model of object representation, I have simply borrowed Piaget's model of object representation and stated it in interactive terms (Piaget, 1954). The reason I can do this is that both Piaget's model and interactivism are action based models of representation and cognition. They are within the general framework of pragmatism, in which action is taken as fundamental to the study of mind, rather than consciousness understood in a passive visual metaphor (Joas, 1993). The pragmatist framework is fundamentally different from the classical encoding approaches. It is also much more recent, having been introduced by Peirce only a little over a century ago. In a general sense, I am arguing that pragmatism is the direction of solution to millennia old problems that cannot be solved otherwise. This, of course, does not mean that pragmatist models cannot be in error too (Bickhard and Campbell, 1989), but only that classical encodingist models, foundationalisms whether of empiricist or rationalist sort, are ultimately dead ends, however complex and never-ending might be the exploration of the labyrinths that they generate.

This kinship to Piaget also provides at least the outline of the solution to another challenge to the interactivist model: how could such a model account for abstract representations, such as of electrons or of numbers? What is the realm, the environments, for those representations to interact with? Piaget's model must be modified more than for object representations, but the basic idea is his (Bickhard, 2003/2004; Campbell and Bickhard, 1986).

CONSTRUCTIVISM AND EVOLUTIONARY EPISTEMOLOGY

Encoding models can tempt the presupposition of a passive mind: neither the wax nor the transducing retina need to be endogenously active. But there is no such temptation regarding interaction systems. The world could not impress a competent interaction system into a passive mind. Interaction systems must be constructed. Pragmatism forces constructivism.

Furthermore, unless we assume that the organism already knows which constructions will succeed, these constructions must be tried out and removed or modified if they are not correct. Pragmatism forces a variation and selection constructivism: an evolutionary epistemology (Campbell, 1974).

If this constructivism is recursive, in which prior constructions can be used as resources for future constructions, then as more becomes constructed about a domain, the resources available for learning still more increase, and learning becomes better in such domains. Learning becomes domain specifically enhanced. Conversely, some constructions may be unlikely unless certain prior constructions are available. Such dependencies in the possible trajectories of constructive learning constitute development.

Finally, the constructive processes may themselves be recursive, in which the construction procedures are themselves constructed, and may become specialized for various domains—a kind of metarecursivity (Campbell and Bickhard, 1992). It is worth noting that Piaget's model is recursive, but not metarecursive: equilibration stays equilibration throughout development. It is also worth noting that encodingisms can involve a kind of constructivism in which representations are constructed out of basic atomistic (innate) representations, but it is a nonemergent form of constructivism, a desiccated shadow of the richness of interactive constructivism. In fact, encodingisms can strongly motivate the position that there is no genuine development at all (Fodor, 1983; Piattelli-Palmarini, 1980).

SCAFFOLDING AND SELF-SCAFFOLDING

A recursive constructivism generates an interesting and important model of scaffolding, one that makes sense of such notions as self-scaffolding. Consider a task that is beyond a child's current capabilities and that is too complex relative to the child's current knowledge and skills to be capturable in any reasonable construction from resources currently available. To solve the task would require a complex construction that is highly unlikely for the child to hit upon.

Conversely, trial constructions that the child might attempt will be selected out because they do not have the necessary complexity to manifest the required skill. In consequence, such trial constructions will be lost as potential resources for further constructive tries.

Suppose, however, that some of the selection pressures that would make some of those trials fail were themselves somehow blocked or set aside. Under such conditions, some of those constructive trials might remain, available for further constructions, that would have been eliminated otherwise. If a constructive trajectory of nearby, not so complex, constructions can be made viable by blocking selection pressures in this way, perhaps each one building on the previous, they might form a constructive path that would end with the full skill or competence, such that the blocking of selection pressures is no longer needed. In such a case, by blocking selection pressures that would otherwise hold, the child's constructions might be *scaffolded* to be able to reach the general complex construction that might otherwise be out of reach.

This is a functional notion of scaffolding. It differs fundamentally from classic models for which Bruner first introduced the metaphor (Ratner and Bruner, 1978; Bruner, 1983): In those models, scaffolders would provide knowledge, usually coordination knowledge, that the child does not currently have, thus making the abilities of the child together with that external coordination competent to some task that he or she was not otherwise capable of, and thereby making that coordinative knowledge available for interiorization by the child. Interiorization (as well as Piaget's internalization) are unfortunate metaphors for unmodeled processes. They motivate the assumption that what is constructed internal to the child is structurally iso- or homomorphic to some external structure. This is a form of encodingism, and a confusion between descriptions of task capabilities and explanations of them (Campbell and Bickhard, 1986).

In any case, providing (coordinative) knowledge to a child that that child does not currently have is one way that selection pressures can be blocked. But it makes no sense to postulate a child, or anyone else, providing knowledge to him- or herself that is not already present, while it does make sense to consider a child learning to block some selection pressures. The functional selection blocking conception of scaffolding is broader than that of interiorizing knowledge (and not as theoretically suspect) and it makes perfectly good sense of the notion of *self-scaffolding*.

I have argued, in fact, that the development of self-scaffolding skills—e.g., learning to break problems down into subproblems, moving to simpler and ideal cases, making use of resources currently available that may not in general be available, and so on—constitutes a major field of development in its own right. Insofar as we *learn to learn*, self-scaffolding skills are at the center (Bickhard, 1992). Note that the functional model of scaffolding, thus of self-scaffolding, is not available to any model of learning and development that is not at least recursively constructive. Blocking selection pressures only makes sense if the "intermediate" "scaffolded" constructions can be made use of in later constructive trials, and that *is* recursive constructivity.

I have called this a major field of development rather than a domain of development because the skills involved in self-scaffolding will themselves tend to be significantly domain specific. Self-scaffolding mathematics problems can involve quite different skills than self-scaffolding social interaction problems. So, self-scaffolding is at the center of learning to learn for each domain, but it has at best partial generalization across domains. Nevertheless, it is central to development—and should be central to education: The scaffolding of the development of self-scaffolding skills should be at the heart of educational design and practice.

But, of course, it is not. My own sense is that the nurturing and scaffolding of self-scaffolding is in fact central to good teaching, but that it tends overwhelmingly to be intuitive and semiclinical. It cannot be theoretically well guided because few models of learning and development can even support the recursive constructivism involved, and even fewer have developed the theoretical notion. Certainly the dominant computationalist, or connectionist, models can make at best a kind of ad-hoc gesture toward constructivism, not to mention recursive constructivism, and, therefore, can provide at best theoretically ad-hoc rules of thumb as guidance. But, of course, they mostly don't do that much either.

COMPUTERS, EDUCATION, AND ERROR

Optimal education, then, will take into account the endogenous interactive and constructive activity of the mind. It will recognize that all learning and development is on the basis of, in the context of, and using the resources of, what has been constructed before. That is, all learning and all development is context sensitive, not only in the sense of the current environmental context, but also the prior constructive context. And it will recognize that all learning and development involves error, not just as a matter of unfortunate fact, but as being central to the nature of understanding and rationality: We do not understand "right answers," or rational thought, unless we understand how they avoid relevant errors (Bickhard, 2002). We are not tempted to think of optimal learning as being errorless when thinking of physical skills—such learning is always by way of progressive approximation through error space—but we *are* tempted to think so in cognitive realms if we presuppose some version of rings pressing themselves into passive minds.

One crucial sense in which both error and context are involved in learning and development is in the development of self-scaffolding skills. Blocking constructions from the selection effects of potential errors is at the heart of scaffolding, and which potential errors are relevant to block will depend on what the child already knows, on what prior constructions are available.

Much of this context sensitivity is domain, and sometimes even child, specific. Many of the relevant error spaces are similarly domain and sometimes even child specific. Experienced and skilled teachers have mastered significant portions of these realms of consideration, but, as mentioned, this is generally in an intuitive manner. All too often, we are left with learning environments in which right answers are provided, and, perhaps, some sorts of explanations, but rarely is any attention expended on the errors that might be made and that are being made by this particular child. Too often, even good students can come away after having "learned" a lesson with their prior misunderstandings of phenomena still intact.

Taking error and potential error into account, especially with the potential for child specific versions of these, can be beyond what can be done in a classroom, and, across children (or adults) and across domains, likely beyond the capacities that any teacher can learn over even decades of experience. But knowledge of what kinds of errors have been historically made in a given domain, why they were decided to have been errors, and the kinds of errors made by a range of learners in that domain (which tend in part to track historical errors) can be developed and can be made part of the available resources for intervention using computers. Computers provide the possibility of taking the intuitive and individualized skills of good teaching and making them available to all learners. This would not be merely the computer as massive storage and retrieval technology, but an ability on the part of the system to track assumptions and presuppositions in learners' interactions, and intervene with respect to the most important, the most incorrect, and the most troublesome of those "learner contexts"—especially those that make the most difficulty in scaffolding the construction of more comprehensive knowledge.

Wu (1993), for an illustrative example, developed two curricula for teaching evolutionary theory. One was based on presenting and explaining evolution in its current updated form—an introduction to the best that contemporary science has to offer, as is usual in science curricula. The other was organized around the history of the development of the theory of evolution, with special emphasis on the errors involved in that history: what they were and on what grounds they were eventually decided to be errors. This was done on the underlying assumption that students' errors are likely to at least in part get stuck on false conceptions that others have made in the past. As might be expected, the later curriculum produced significantly better and deeper understanding of the theory.

Such an (error focused) history of every relevant domain is too vast for individual instructors to master; but a computer would have no capacity problems in this regard. Furthermore, these evolutionary theory curricula were fixed, and not sensitive to any individual characteristics of the students; but a computer could potentially construct hypotheses about particular student's misconceptions, and base future interactions with the student on such tentative conceptual diagnoses.

The computer, then, is not just storage and retrieval, it is also interactive itself, and capable of learning about individuals as well as about knowledge and error. Ultimately, all are important, but all of that is beyond what most people can keep track of. In this sense, I am suggesting that an important role for computers in education would be similar to computers as aids to diagnosis in medicine: there is an enormous amount that is potentially relevant, though in any single case, most of it is not relevant. But it is very useful to have that "enormous" amount of positive knowledge, error knowledge, and ability to detect presuppositions, both correct and incorrect, available.

In a perhaps ironic sense, then, I am suggesting that one of the important possibilities made available by the computer is its ability to handle the multiple and complex roles that *error* plays in genuine learning and development. Especially the scaffolding of the development of self-scaffolding.

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