DOCUMENT RESUME

ED 423 846 IR 019 067

AUTHOR	Land, Susan M.; Hannafin, Michael J.
TITLE	Learning in Open-Ended Technology Environments: Problems and Issues.
PUB DATE	1998-02-00
NOTE	12p.; In: Proceedings of Selected Research and Development Presentations at the National Convention of the Association for Educational Communications and Technology (AECT) Sponsored by the Research and Theory Division (20th, St. Louis, MO, February 18-22, 1998); see IR 019 040.
PUB TYPE	Opinion Papers (120) -- Reports - Descriptive (141) -- Speeches/Meeting Papers (150)
EDRS PRICE	MF01/PC01 Plus Postage.
DESCRIPTORS	*Communication Problems; *Computer Assisted Instruction; Computer Mediated Communication; *Constructivism (Learning); Courseware; Educational Technology; Information Technology; Instructional Effectiveness; Interaction; *Learner Controlled Instruction; Learning Strategies; Open Education; Student Needs; User Needs (Information)
IDENTIFIERS	*Open Ended Learning Environments; Technology Based Instruction; Technology Mediated Interactive Learning

ABSTRACT

This paper critically analyzes problems and issues related to learning with open, technology-based environments. Theoretical assumptions that underlie learning in this type of environment are clarified in the first section. The second section addresses imitations in adaptive capabilities of technology, including: the learner relies upon feedback that is contingent upon learner actions; when learners maintain naive beliefs and fragmented understandings, the system must be able to present consequences and data that can be perceived as consistent or inconsistent; learners may not perceive the implications of such responsive data; and interactions may be distorted and misunderstood. The third section covers the importance of shared meaning as a necessary means toward increasing both partners' (i.e., the learner and the system) understanding each other's point of view at important points during the interaction. Sources of misunderstanding are then discussed, including: perceptual limitations of visual cues; biased and confounded meanings; failure to share meanings within system boundaries; and incongruent meta-level approaches. (Contains 44 references.) (DLS)

Learning in Open-Ended Technology Environments: Problems and Issues

Susan M. Land
The Pennsylvania State University

Michael J. Hannafin
University of Georgia

Abstract

Contemporary computer-based environments use the capabilities of technology to create contexts which require and afford students the opportunity to engage in authentic problem solving by generating, testing, and revising hypotheses; exploring and manipulating components of the environment; and representing and reflecting on what they know. By design, such environments require sophisticated levels of cognitive functioning including higher order cognitive and metacognitive functioning. Learning in open learning environments relies on a shared, reciprocal, and co-constructed understanding of events between the learners and the learning environment. The purposes of this paper are to critically analyze problems and issues related to learning with open, technology-based environments.

Open-ended, learner-centered environments are designed to support individual intentions to construct personal meaning by engaging in authentic projects or solving problems. The philosophical and theoretical assumptions of student-centered learning are fundamentally constructivist and situated (Jonassen, 1991; Hannafin & Land, 1997). Methods for supporting personal knowledge construction, such as problem-based learning (Savery & Duffy, 1996), anchored instruction (Cognition and Technology Group at Vanderbilt, 1992), situated cognition (Brown, Collins, & Duguid, 1989), project-based learning (Blumenfeld, et al. 1991), and open learning environments (Hannafin, Hall, Land, & Hill, 1994), share those constructivist and situated assumptions about learning and aim to provide contexts and structures that support meaningful, learner-centered interactions.

In concert with these methods, technology is often employed as a tool or mediator of the process, functioning as cognitive tools for experimentation, manipulation, and generation of ideas. The result is a complex, reciprocal interaction of learning *with* technology: tools, resources, and scaffolding facilitate actions that augment thinking, and meaning is built upon, and governed by, the results of these (learner-driven) actions (Salomon, Perkins, & Globerson, 1991. Achieving these results, however, requires continual evolution and sharing of meanings within the learner-technology partnership. The purposes of this paper, then, are to clarify (1) the theoretical assumptions that underlie learning with open, technology environments; (2) limitations in adaptive capabilities of technology; (3) the significance of two-way, shared understanding; and (4) problems and issues that can arise during the co-construction process.

Learning with Open Learning Environments: Processes and Assumptions

OLEs are technology-based environments that require learners to deploy unique knowledge and skill to solve complex and authentic problems (Hannafin, Hall, Land, & Hill, 1994). They use the capabilities of technology to create contexts wherein complex concepts can be represented, manipulated, explored, and revised. Rich information resources and computer-based tools are woven into contexts that create virtual spaces to support problem-solving and higher-order thinking. Examples of OLEs include computer-based microworlds (see Microworlds Project Builder, 1993); resource-based hypermedia environments for researching and linking ideas such as cognitive flexibility hypertexts (Spiro, Feltovich, Jacobson, & Coulson, 1991); and collaborative knowledge construction environments for sharing and linking of evidence, questions, and products (Linn, Bell, & Hsi, in press). OLEs foster development of understanding by providing opportunities for learners to identify, test, and revise ongoing theories as they solve complex problems and integrate multiple perspectives (Land & Hannafin, 1996).

The centrality of the learner in defining meaning is considered a necessary requirement for combating problems of over-simplified (Spiro, et al., 1991), "compliant," (McCaslin & Good, 1992) and decontextualized thinking (Cognition and Technology Group at Vanderbilt, 1992). Understanding is assumed to be best supported

IR019067

when it is rooted in personal experience and is accomplished via exploration, interpretation, and negotiation (Hannafin & Land, 1997). According to Land & Hannafin, (1996) understanding evolves continuously and dynamically, as ideas are generated, tested, and revised.

While assumptions and theories of student-centered learning are provocative, many questions remain about the efficacy of such environments, specifically those that are technology-based. For example, evidence indicates that learners do not always use open systems in ways that support knowledge construction, so they fail to evolve conceptions significantly, and may not use the *affordances* of technology to develop meaningful understanding (Atkins & Blissett, 1992). Rather than engaging in reflective learning, learners often deploy random instead of reason-based actions, search for "answers" instead of generating and testing problems (Wallace & Kupperman (1997), and sustain naive beliefs (in the face of repeated conflicting evidence) instead of evolving them (Land & Hannafin, 1997). Perkins (1985) has warned against the notion of a "fingertip effect" -- an over-reliance on assumptions about what an environment *can* afford -- in that the existence of an opportunity does not imply that it will be shared or engaged.

Explanations for the lack of effectiveness include limitations of the system to adapt to student needs, unanticipated implementation requirements of teachers, and a lack of empirical grounding for selected approaches, methods, or desired outcomes (Hannafin, Hannafin, Land, & Oliver, 1997). Additionally, a host of psychological and motivational variables may also impact understanding in open systems. In order for meaningful learning to occur, systems rely significantly on the intentions, actions, processing, and regulation mechanisms of the learner. Regardless of contexts or content domain, learners must assume primary responsibility for the learning process. This charge *requires* them to derive goals and problems, make informed decisions, take reason-based actions, process information and feedback, and monitor their needs and approaches on a meta-level. Furthermore, in order to continually evolve conceptions, learners must derive interpretations, test them for their validity, and evaluate their utility in light of confirming or conflicting data. These requirements for effectively functioning in learner-centered systems are demanding and exacting and not typically possessed by students. Yet, assumptions dictate that learners are not only capable of meeting such psychological requirements, but they are also imminent when supported by the system context.

Co-Construction with Technology: Issues in Adaptability

A fundamental premise of constructivist learning is that learners evolve understanding as a direct result of encountering "discrepant events", failed goals, unmet expectations, problems, curiosities, or cognitive dissonance (Piaget, 1976). This implies that learners naturally develop understanding of the surrounding environment by attempting to make sense of it and reconcile deviations from expectations. Yet, clearly there are also instances where "natural teaching" -- a reactive response to student needs when understanding is arrested -- is also effective for guiding students to a more refined conceptual level (Schank & Cleave, 1995). The zone of proximal development implies that meaningful learning occurs as a result of learner engagement in activities that are "scaffolded" by social, material, or technological faculties (Vygotsky, 1978). Thus, the development potential of learners is extended with the help of dynamic support that assists them in building upon initial understanding. However, the learner's ability to perceive and act upon a "need to know," as well as the environment's ability to respond to these needs, are critical to realizing effective interaction within the zone of proximal development.

Yet, re-directing, responding to, or meeting learner-generated needs within the theoretical "zone" is often problematic for technology-enhanced environments. One reason for this difficulty is that explicit, a priori identification of expected student needs are difficult to predict and thus fulfill. Whereas general scaffolding can be provided (e.g., help resources, instructional support, guiding questions, hints, or prompts for reflection), truly dynamic or "intelligent" responses to unique issues, interpretations, or questions may not be possible to satisfy through technology support alone. Potential difficulties are exacerbated when learners deploy idiosyncratic preferences and approaches that are not supported (nor sometimes desired) by the design (e.g., searching for a right answer vs. using tools to experiment). When learners' goals are dissonant from system goals, interactions become distorted, and the environmental support is counterproductive.

Limitations in adaptive capabilities of OLEs are significant for several reasons. First, the building and evolving of learner understanding is contingent upon feedback that is correspondingly contingent upon learner actions. The environment affords cognitive performance only when learner intentions and perceptions are consonant with system goals. With microworlds and simulations, for instance, learners must construct a "working model" of their understanding that is progressively honed via manipulation of system features. Through interaction, learners make their ideas explicit and clarify and extend both their understanding and implicit models (Driver & Scanlon, 1988). Feedback about the efficacy of the model is essential for critical examination, reflection, and conceptual development. As intentions and actions are increasingly linked with the feedback (and subsequent processing of the feedback), understanding is generated and examined critically.

Second, the importance of adaptive feedback becomes even more critical when learners maintain naive beliefs and fragmented understanding that are extremely resilient to change (Chinn & Brewer, 1993). Furthermore, they are *expected* to hold naive theories that will be represented in their actions and in their intentions to test their validity. Yet, evolving enduring beliefs requires repeated exposure to counter-examples that indicate how existing beliefs are limited in explanatory power (Karmiloff-Smith & Inhelder, 1975; Piaget, 1976; Vosniadou, 1992). Schön (1983) notes: "Doing extends thinking in the tests ... of experimental action, and reflection feeds on doing and its results...It is the surprising result of action that triggers reflection..." (p. 280). Thus, the system must be able to "understand" formative theories-in-action, represent the consequences or effectiveness of them, and provide responsive data that can be *perceived* as consistent or inconsistent.

Yet, even when the system provides responsive feedback about learners' models, if they fail to relate that feedback to their theories, they may not perceive how data support or contradict their beliefs. Intuitive theories (e.g., impetus theories of force and motion [Driver & Scanlon, 1988], beliefs that the Earth is flat, and beliefs that density is not a factor in the buoyancy of an object) are so consistently reinforced through personal experience that they form the foundation of firmly-established, though often fundamentally flawed, theories. In some cases, underlying beliefs are so entrenched that learners fail to consider testing them. If one truly believes that heavier objects sink and lighter objects float, for instance, it is unlikely that one will intentionally seek out opportunities to prove it wrong.

It is unlikely that problems in meeting the requirements or assumptions of student-centered learning happen unilaterally, i.e., that the locus of the problem lies solely within the learner (i.e., he or she is incapable of representing meaning or accurately perceiving feedback) or solely within the system (feedback is incapable of accurately modeling learner understanding or responding to individual needs). Rather, it is more likely that breakdowns occur as a result of distorted *interactions* that occur. Thus, the success of a constructivist environment hinges upon a shared, reciprocal, and co-constructed understanding of events and *intended* meanings during critical or teachable moments. That is, in order to build upon understanding in meaningful ways, perceptions, intentions, approaches, interpretations, questions, and feedback must be *understood* or *shared* among participants. This assertion defines critical components of the process of progressive negotiation and differentiation of meaning: learners must generate understanding that is based upon existing beliefs as well as responsive feedback from the system (and/or others); the system must then represent or model the intended interpretation and provide feedback regarding its efficacy; the learner must then perceive the intended meaning of data or feedback and refine interpretations. The cycle continues until learners identify beliefs, test them for their validity, and evolve them based on responsive feedback and scaffolding from the system. Thus, in order to support reciprocity and sharing of meaning, both models must be adaptable or are able co-construct. In this sense, meaning is based upon a *shared* overlap of understanding between the learner and the system.

The remaining sections detail issues related to the notion of *shared meaning* in constructivist, technology-based systems and identify potential sources of misunderstandings.

The Importance of Shared Meaning

Shared meaning assists both the learner and the system (or instructor or other learners) to increase the accuracy of, or decrease the potential distortion of, the co-construction process. Most teachers know all-to-well how easy it is for misunderstandings to take place. It is not uncommon to hear statements from learners such as "I thought you meant ..." or "I didn't realize what you meant by ..." or "I assumed that this meant..." when recognizing that misunderstandings have occurred. Upon receiving such feedback, most teachers can adapt their teaching or communication methods to clarify the meaning, redirect the student's understanding, or to circumvent similar misunderstandings from taking place in the future. Engaging in two-way conversations allows both participants to check to see if they are understanding each other and recast or revise explanations accordingly.

Shared meaning with OLEs implies a *functional* relatedness between a set of meanings and messages shared by both the learner and system. This does not imply that meanings are communicated isomorphically; rather, that important components of one message are received and used as the basis for response by the other. There is no "one way" to respond or make sense of a meaning. There is simply a congruence among all messages. In essence, shared meaning is process that ensures that the system and the learner are operating on the same "page" or on the same collection of meanings.

In action, the concept of shared meaning involves a dialectic or dynamic communication of meanings. Messages are continually sent back and forth, as learners perceive important variables, generate hypotheses, and test for their veracity. When learners communicate messages to the system through the interface, the system is programmed to respond to them. For instance, if a learner is exploring the effect of interest rate on monthly housing payments and increases the interest rate, the system processes it and returns a message that is based upon the initial input. That is, the system sends a message about the change in calculated output based upon the learner's request to increase the interest rate. The learner then uses this message as the basis for revising an interpretation, generating a new hypothesis, or confirming an expectation. The system response should always be contingent upon the learner's original meaning and modeled to the learner. Then, a collection of new meanings or responses are generated by the learner, yet they must be built upon original meanings and also accommodate the system's message. The cycle is repeated over time, with every message being used to refine a preceding one, until the learner decides to end the interaction.

The shared meaning process is significant in that it lies at the root of many assumptions about how understanding evolves with OLEs. It is assumed, for instance, that the learner can represent and communicate a meaning to the system. It is further assumed that the system can interpret the meaning, model it, and represent a response that can be discerned by the learner. Finally, it is assumed that the learner will accurately perceive, understand, and appropriate the message sent by the system, without altering its intention or ignoring it altogether. These are high expectations, particularly when considered in light of the fact that a machine cannot understand a message that it has not been programmed a priori to process.

Rather than judging the "correctness" of learners' responses, the system seeks convergence of system and learner models. Initially, learner models may be quite distinct from how they ultimately develop. Yet, through interaction with the system, initial and desired models become more aligned with each other within an acceptable range of confidence as defined by a community of practice.

As such, shared meaning should not be considered as a *goal* in and of itself. A tape recorder, for instance can accurately model or report exactly what has been dictated; yet a tape recorder does not understand. Rather, shared meaning is a necessary and important *means* toward increasing both partners understanding of each other's point of view at important points during the interaction. It is intended to emphasize theoretically the need for both the learner and the system to occupy a mutual and as complete understanding as possible of the other's intended meanings. This does not imply that complete understanding of all of the possible meanings of the system nor all of the possible meanings of the learner are either possible or desired. But, it is assumed likely that en-route interactions between the system and the learner will result in a progressive negotiation and development of understanding. Shared meaning is important for open systems because, when it occurs, interpretations can move forward from a point of understanding versus from a point of misunderstanding.

Sources of Misunderstanding

When the shared meaning process breaks down during open-ended learning, distortions in approaches, perceptions, or interpretations result. The purpose of this section is to illustrate where and how such points of departure can occur. While it is likely challenging or unnecessary to foster complete sharing of meaning for all possible learner-system interactions, specific types of interactions at critical points in the process can seriously impact the extent to which meanings evolve.

Perceptual Limitations of Visual Cues

Meaning is shared in instances where learners connect system data with personal meaning, and subsequently expand ways of explaining phenomena. As a result of the exchange, informal understanding becomes more clearly connected to the experiences that informed them and to formalized concepts. Accordingly, system and learner models are continually refined and merged. Yet, as messages and intended meanings are exchanged, two processes are essential for them to be shared. First, intended meanings must be accurately perceived by the learner and/or the system. Second, observed data must be accurately appropriated with interpretations that are constructed. For instance, if a learner virtually manipulates the effect of mass on an object's acceleration, and the system provides feedback indicating that the increase in mass did not increase its acceleration, it is essential that the learner is able to *perceive* that acceleration has not increased. Furthermore, if the learner concludes from that feedback that two objects of different masses will fall to the Earth at the same speed, he or she has constructed a meaning that is consonant with the message sent by the system and is linked to empirically-based observations. Breakdowns in either the accurate perception or appropriation of system messages can result in distorted conceptions. In order for understanding to evolve based on shared meanings, learners must induce personal models to unify multiple system concepts, accurately connecting factors and influences into wholes versus parts.

The ability to draw accurate conclusions based on empirical data is integral to scientific inquiry (Roth & Roychoudhury, 1993). Similarly, during the shared meaning process, learners must also stay proximal to the data -- i.e., system feedback is accurately perceived and acted upon and *related* meanings are used to annotate and understand the data. Drawing conclusions based on accurate perceptions is critical because understanding is initially built as learners attempt to make judgments regarding cause and effect (e.g., "when I decreased mass, there was no change in acceleration"); Understanding evolves as learners perceive information inconsistent with a theory (e.g., "I expected that the heavier object would fall faster but it did not"), provide an explanation, and collect data to confirm or refute it. Thus, the process of both building and evolving meaning is contingent upon *accurate* perception and connection of data and events occurring in the system (accuracy is defined as the *intended* meaning of the message sent by the system).

However, limitations in perceptual processes can lead to problems in establishing cause-effect relationships or to the development of conceptions based upon faulty presumptions. Rieber (1995), for instance, details a story of Percival Lowell, a prominent astronomer at the turn of the century, who serves as an example of how inaccurate visual perceptions can lead to erroneous conclusions. Using the telescopic technology available at the time, Lowell reported the spotting of long crossing lines on the Martian landscape. Lowell concluded from these observations that the lines were the remnants of canals constructed by an ancient civilization. Unfortunately, his perceptions (and consequently interpretations) were inaccurate, in that the canals turned out to be optical illusions.

This same type of analysis can also be applied to learners using visualization tools in open environments, due to the use of visually-based feedback that is often presented with ambiguous meaning or fidelity. OLEs often use dynamic displays of numerical data or animation to represent visually the effects of a learner's actions, rather than directly tell the meaning and interpretation of events. Many simulations or visualization tools such as *Space Shuttle Commander, ErgoMotion, Geometer's Sketchpad,* and *Interactive Physics* model the effects of learner input or designs via animated and/or video simulations (Rieber, 1992; 1995). The visually-simulated outcomes provide data regarding the extent to which learner designs functioned and/or changed. From this feedback, learners refine conjectures and hypotheses and confirm or refute expectations.

To illustrate, a learner attempting to maneuver a spacecraft in *Space Shuttle Commander* can see the result of applying a lighter mass to the spacecraft by watching it move across the screen and comparing it to the animated results of applying a heavier mass. Yet, following this animated feedback, the learner might inaccurately *perceive* that the spacecraft moved faster when he or she applied a lighter mass. The fact that the object may *not* have increased in speed contingent upon mass is inconsequential to the fact that the learner perceived that it did in fact accelerate. In this instance, the message conveyed by the system (i.e., mass did not impact acceleration) was not shared by the learner; rather it was confounded with inaccurate perceptions of visual information (i.e., it went faster when I decreased mass). From this initial misperception, it is not implausible to expect that distorted conclusions would likely follow.

Utilizing less visual forms of feedback, such as illustrating changes in numerical values, may not alleviate the tendencies of learners to rely heavily on visual cues as the basis for information. To illustrate, numerical data are often provided to learners in concert with animated, simulated feedback. Yet, Land and Hannafin (1997) reported that learners heavily relied upon video simulations of a roller coaster to judge relative differences in its speed, and failed to seek numerical data to confirm the speed, even when they were available in the form of data points. In this example, judging precise differences in speed was not possible using visual data alone. Thus, most errors in interpretation were due to inaccurate perceptions of visual data from the system, without deeper processing of the numerical data that could have been used to confirm or challenge meaning.

A reliance on literal interpretation of visual cues is likely due to novice learner's focus on superficial or surface features of a problem (Chi, Glaser, & Rees, 1982). Novice learners tend to confuse visibility with relevance and apply little consideration to the underlying logic of their selection (Petre, 1995). Thus, perceptual limitations of learners can affect the "pragmatic precision" (Hawkins & Pea, 1987, p. 296) or degree of exactitude sufficient for explanation. But, while novices may not require precise sources of evidence in order to establish meaning, they nonetheless *use* what they perceive. This phenomena is known as *top-down processing* -- "initial information triggers an early interpretation against which all subsequent information is judged" (Rieber, 1995, p. 53). In instances where learner perceptions conflict with meanings intended to be conveyed, misleading attributions of cause and effect result that become difficult to further test, alter, or refine. Misunderstandings can further endure in the likely event that the system is unable to detect that faulty perceptions have been constructed.

Biased and Confounded Meanings

Distorted conceptions are not solely apparent as a consequence of misperceived visual data. Learners are also susceptible to the effects of biased, preconceived, or deeply entrenched intuitive beliefs that can influence the precision with which messages are perceived or the likelihood of existing beliefs to change (Driver & Scanlon, 1988). Meanings are filtered through existing beliefs and experiences, and they become distorted when learners add to, ignore, or change system messages to fit existing conceptions (without evaluation). When this phenomena occurs, learners perform the cognitive equivalent of "seeing what they want to see." Thus, the issue for open learning environments is not that learners hold strong beliefs that are at odds with those represented in the environment; on the contrary, novice learners are expected to hold naive beliefs. Rather, problems occur to the extent that messages are altered or distorted to fit into existing belief systems, without evaluation of whether the data provides evidence to the contrary.

Wilson and Brekke (1994) refer to this phenomena as "mental contamination" and define it as "the process whereby a person has an unwanted judgment, emotion, or behavior because of mental processing that is unconscious or uncontrollable." (p. 117). This psychological mechanism results in automatic attributions of meanings that are useful during new learning -- it helps learners to quickly make order out of disorder. Yet, in order for naive beliefs to evolve in open systems, learners must recognize conflicting data and eventually evaluate biases or shortcomings in thinking. Perception of dissonance and "meta-conceptual awareness" (Vosniadou, 1992) are necessary triggering mechanisms for evaluation to occur.

Research on the effects of preexisting beliefs, however, indicate that they are remarkably perseverant and resistant to change (Champagne et al., 1985; Kardash & Scholes, 1995; Perkins & Simmons, 1988). Social theories, such as beliefs about AIDS, capital punishment, or prejudice, are enduring and often difficult to alter, even in the face of examples that counter beliefs (Kardash & Scholes, 1995). Wilson and Brekke (1994) illustrate the unwanted impact of existing social beliefs on actions in the following excerpt:

> Professor Jones is grading papers from a small seminar. When grading Hernandez's paper, undesirable mental processes are triggered by the fact that Jones dislikes Hernandez and knows that Hernandez is a member of a minority group. That is, Jone's dislike and prejudice taints her evaluation, such that the evaluation is more negative than it would otherwise be. Furthermore, assume that Jones would agree that this is unfair and would prefer not to be influenced by her prejudice. This example, then, fits our definition of mental contamination in that Jone's judgment was influenced by unwanted agents (her prejudice). (p. 119).

In this example, the data (the quality of a student's paper) are evaluated in light of existing beliefs that are undesirable and deeply rooted in experience. A disconnect exists between the accuracy of the message sent by the student, and the way it was interpreted and acted upon by the instructor. In order for the biased theory to be weakened and the data to be evaluated accurately, a competing theory must be strengthened as the legitimacy of the original theory is questioned (Holland, Holyoak, Nisbett, & Thargard, 1986).

Yet, novice learners (particularly young learners) do not spontaneously test theories to determine if their thinking is biased (Karmiloff-Smith & Inhelder, 1975; Land & Hannafin, 1997). Rather, they require repeated exposure to counter-examples before gradually recognizing limitations in thinking. But, even when conflicting data about the usefulness of beliefs are repeatedly provided, initial theories may remain largely unchanged. Research examining the evolution of learner beliefs with open learning environments indicates that learners often fail to perceive and interpret data as being inconsistent with existing theories (Land & Hannafin, 1997). Even when learners were confronted with obvious conflicting evidence, they failed to act on the inconsistencies. Instead, they either changed theories temporarily, without acknowledging the previous theory, or discounted the data as an exception rather than attempting to explain it. Paradoxically, when confronted with counter-examples based upon data that is ambiguous (e.g, imprecise visual data), learners often manipulate the data to actually *strengthen* or confirm the existing theory.

Failure to Share Meanings within the System Boundaries: The Situated Learning Paradox

Another assumption underlying the design of OLEs is that learning is optimized when it is situated in an authentic context (Hannafin et al., 1994). Learning is facilitated when opportunities to connect everyday knowledge to new contexts are provided. As learners connect system experiences with prior knowledge, they access existing frameworks that strengthen and elaborate new understanding. It is widely recognized that integrating new knowledge with personal experiences results in more meaningful learning (Mayer, 1984; 1989).

When learners access and use related experiences to construct and annotate meaning, they inherently extend thinking beyond the boundaries delineated by the system. That is, they access experiences that are not represented in, nor are they often able to be represented in, the specific environmental context. This means that meanings accessed from personal experiences will not be communicated to, nor modeled by, the system. As stated previously, meanings are shared as they are represented and communicated via available interface input/output options. In order for meanings to be reciprocally shared, the system's response to a learner's meaning must embody the intended model or message as well as additional information about its veracity. When learner meanings are rooted in prior experiences and cannot be tested within the system boundaries, they are unable to be accommodated or shared by the system. While this is not inevitably problematic, it nonetheless illustrates limited capabilities of the system to adapt to and model learner meanings that are rooted in prior experiences.

To the extent that functionally *related* meanings are accessed from prior knowledge, problems are less significant. Take for instance a hypothetical learning environment where learners can explore the concept of buoyancy and water displacement. The interface might revolve around a virtual swimming pool, where learners can observe how objects of various weights, sizes, and densities float or sink. The leaner may observe, for instance, that a small, highly dense object can sink while a large, less dense object of the same mass does not. Based on this observation, a learner might make the following connection to prior experience: "This sounds like what happens when I curl up into a ball in a pool: I sink. But, when I extend my arms and legs on the surface, I float. But, I have the same weight." This connection represents a functional relatedness to the concept represented: The meaning constructed by the learner contains both the "message" that the system intends to send (i.e., density is a more important factor than weight or size in buoyancy) as well as other *related* meanings based on prior experiences (e.g., "I sink when I curl into a ball vs. when I am extended." These meanings are functionally congruent and, in this one interaction, could be considered shared. While, it still cannot be directly tested in or communicated to the system (unless system can spontaneously change its interface to include options for manipulating the weight of a child in a curled vs. extended position), the result is a richer conceptualization that is now strongly rooted in experience.

Yet, while links to prior knowledge enhance the potential for transfer (Brown, Collins, & Duguid, 1989), they also increase the likelihood that learners will draw upon incomplete and often inaccurate understanding which form the basis of faulty theories. To illustrate using the same buoyancy example, a learner could also conceivably make the following connection to personal experience: "When I wear flotation devices on my arms in a pool, I float. When I don't, I'll sink. I don't sink with the floats because they make me lighter." Incomplete conceptions, such as this, are typical in content areas like science where everyday experiences are at often odds with scientific conceptions (Carey, 1986).

Most learners think that heavier objects fall to the Earth faster and lighter objects float. They also have a collection of personal experiences to support these intuitive theories. The result is a set of robust conceptions that are rooted in personal experience and highly resistant to change. When naive, personal theories are used to inaccurately annotate the meanings communicated by the system, the system is unable to detect or adapt to the conception. Thus, limitations in adaptive capabilities of the system are significant in instances where inaccurate or irrelevant experiences are accessed and used to explain data that is inconsistent with system experiences and *cannot be tested*.

Similarly, Land and Hannafin (1997) noted that learners also referenced prior knowledge and experiences in the *ErgoMotion* roller coaster environment that contradicted, or interfered with, the system's treatment of the concepts of force and motion. One learner referred to the regulating effects of a computer on the speed of the coaster, and the use of brakes and "clamps" for stopping the coaster. She recalled a roller coaster operator telling her that the coaster had brakes and could stop mid-ride. Consequently, she used this information to interpret feedback and drive future actions. She continued to make references to brakes and clamps during remaining use of the system when addressing issues of slowing down and stopping. Her conceptions did not evolve, since they were strongly rooted in experience and could not be tested using the available tools. Consequently, she never confronted evidence to provoke her into questioning these theories. In this case, a belief that the coaster slowed down around the curve (because of brakes or a computer regulating it) interfered with an understanding of force and motion in a context that did not support exploration of the notion.

Such interactions can lead to powerful generalizations since they are linked to prior knowledge but cannot be easily refined using system tools and resources. The effect is further intensified in that prior knowledge and experience are exceptionally robust and persistent. Thus, when learners make connections to prior knowledge, and when they are ill-informed or inaccurate, they cannot be tested within the parameters of the system and thus may endure. While the benefits of building upon meaningful experiences are clear, the challenges of the system to detect and accommodate them remain formidable.

Failure to Share the Rules of Interaction: Incongruent Meta-Level Approaches

OLEs assume that learners are responsible for their own learning and are capable of monitoring the self-directed learning process (Hannafin et al., 1994). The learner is at the center of the environment, both in terms of decisions for using it and ways of making sense from it; instructor or direct information is not available to tell them how to interpret events, nor to monitor the strategic approaches. Consequently, learners invoke their own learning strategies to organize and rearrange the learning process.

Yet, implicit rules for using the system also govern how successfully meanings will be shared. A traditional college classroom, for instance, has an implicit set of rules defined for effective interaction -- i.e., attend class, take and annotate notes, use instructor office hours for help, study for tests and so on. Learners in such environments have some latitude regarding how to study or seek help within the established boundaries (e.g., using study groups; borrowing notes; keeping up with assignments); yet, choosing not to attend class or study for tests, for instance, represent approaches that would not likely lead to success within that given system. An instructor cannot help students develop understanding if they do not use the opportunities that have been afforded them (e.g., attend office hours; use class time for clarification). While strategies and approaches may also depend upon the specific content domain, the implicit rules of interaction must be agreed upon, shared, and understood by both partners at the outset (i.e., teachers and students; students and students; or students and technology).

Similarly, when learning with OLEs, approaches must also be consonant with the rules governing effective use of the environment. For many learners, these strategies and approaches may represent radical departures from standard school-based learning activities. Learners must be able to navigate resources, recognize knowledge gaps and find relevant information, ask driving questions, test hypotheses, and take action to collect and analyze feedback. Incongruent meta-level approaches are significant in that the system is unable to discern whether suitable approaches are being used -- whether a mouse click represents a random vs. reasoned action or whether tools are being used to test theories vs. see what happens.

In order for meaningful learning to occur, both learners and the system must be operating under the same set of assumptions. OLEs require learners to generate hypotheses and to maneuver within the environment, even when knowledge of its rules are incomplete (Holland, et al., 1986). For instance, learners using a thermodynamics microworld might manipulate variables such as surface area, surrounding temperature, and insulation material of an object. They would use data derived from taking action (e.g., testing out a hypothesis that smaller objects wrapped in aluminum will retain heat better) as the basis for addressing a goal and informing future action. Learners use inductive responses (Holland et al., 1986), processing the data that *is* available to begin constructing and refining models.

Problems in effective use of OLEs occur when learners use approaches that are unproductive within that context -- for instance, use of traditional classroom practices within a constructivist environment. In traditional environments, learners collect and learn information prior to using it for deriving or solving problems, often in absence of a meaningful or applied context. The approaches are seldom hypothesis-driven; rather, actions are designed to amass specific information until satisfactory initial insights are acquired. Research on how learners use OLEs indicates that they often rely upon traditional reasoning processes that are unsupported and unsuccessful in the environment (Land & Hannafin, 1997; Wallace & Kupperman, 1997).

Wallace & Kupperman (1997), for instance, found that children often applied a traditional strategy of "finding the answer" to an inquiry- and web-based context. That is, children tended to view the activity as finding an answer to their research question, and "thus reduced the task to finding a single page, the perfect source, on which the answer could be found." (p. 13). The goal of these approaches was to submit search after search until the smallest amount of hits were returned. The following type of interaction reflects this traditional approach:

> "...One pair of students...reacted effusively to small hit lists, singing and calling out 'yes, we got it now...hey you guys, we got it!' when they saw that the number of hits from a search was 18, then reacting with equivalent disappointment when a cursory viewing of the hit list did not reveal an obviously appropriate site: "All these things stink...cause we put in *animals* ... let's delete *animals*." Later, these students produced a hit list with only three pages, and ...exclaimed, "Oh my gosh, we got it!"

In this instance, learners seemed to rely on directed methods for learning in contexts that did not inherently support or promote use of these approaches. When incongruent approaches are used, meanings are communicated according to fundamentally different sets of assumptions. Thus, feedback is less meaningful as learners continue to search for specific answers or information that will not likely be rendered by the system. The result is confusion, disorientation, and frustration (Hill & Hannafin, 1997).

Conclusions

This paper has presented a framework for considering important, but often overlooked, assumptions underlying use of OLEs. Fundamentally, we presume that as learners use OLEs, they perceive relevant information, construct related interpretations, and evaluate discrepancies between their own understanding and the meanings provided by the system. The process by which development of understanding occurs hinges upon a shared, reciprocal and co-constructive sense-making process. Such methods, however, tacitly presume that learners possess the self-regulatory skills needed to make effective judgments, or can be guided to make effective choices through support from the system. Yet, research has indicated that a convergence between initial learner models and desired models do not always transpire (Atkins & Blissett, 1992; Hill & Hannafin, 1997; Land & Hannafin, 1997). The intention of this paper was to emphasize the need for more effective two-way communication of meanings between the system and learner and to indicate where potential misunderstandings can occur.

During recent years, there has been widespread interest in unleashing the capabilities of technology using learner-centered tools and environments. Considerable disagreement exists, however, related to the usefulness of OLEs in supporting problem-solving and learner-centered inquiry. The analysis presented in this paper, in addition to previous research on the topic (Hill & Hannafin, 1997; Land & Hannafin, 1997), have identified problems and issues related to design and implementation of these systems. It is our belief that, in order for technology-based learning systems to evolve, we must begin to isolate what we want to occur, how to design systems to support these goals, and what appears instrumental in influencing effective learning. Indeed, many studies have reported notable benefits of using OLEs to enhance student-centered understanding (Cognition and Technology Group at Vanderbilt, 1992; Harel & Papert, 1991; Scardamalia et al., 1989). Yet, we also believe it is equally important to identify what we *don't* want to occur, what it looks like when the process breaks down, and what appears to be causing the problems to occur. Thus, more complete understanding of the limitations, capabilities, and assumptions of these systems is needed in order to capitalize on the unique potential of OLEs.

References

Atkins, M., & Blissett, G. (1992). Interactive video and cognitive problem-solving skills. *Educational Technology, 32* (1), 44-50.

Blumenfeld, P., Soloway, E., Marx, R., Krajcik, J., Guzdial, & Palincsar, A. (1991). Motivating project-based learning: Sustaining the doing, supporting the learning. *Educational Psychologist, 26* (3&4), 369-398.

Brown, J.S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher, 18*(1), 32-41.

Carey, S. (1986). Cognitive science and science education. *American Psychologist, 41* (10), 1123-1130.

Champagne, A., Gunstone, R., & Klopfer, L. (1985). Instructional consequences of students' knowledge about physical phenomena. In West, L.H.T., & Pines, A.L. (Eds.), *Cognitive structure and conceptual change* (pp. 61-90). Orlando: Academic Press.

Chi, M., Glaser, R., & Rees, E. (1982). Expertise in problem solving. In R. Sternberg (Ed.), *Advances in the psychology of human intelligence* (Vol. 1, pp. 7-75). Hillsdale, NJ: Erlbaum.

Chinn, C. & Brewer, W. (1993). The role of anomalous data in knowledge acquisition: A theoretical framework and implications for science instruction. *Review of Educational Research, 63* (1), 1-49.

Cognition and Technology Group at Vanderbilt (1992). The Jasper Experiment: An exploration of issues in learning and instructional design. *Educational Technology Research and Development, 40*(1), 65-80.

Driver, R., & Scanlon, E. (1988). Conceptual change in science. *Journal of Computer-Assisted Learning, (5),* pp. 25-36.

Hannafin, M.J., Hall, C., Land, S., & Hill, J. (1994). Learning in open-ended environments: Assumptions, methods, and implications. *Educational Technology, 34*(8), 48-55.

Hannafin, M., Hannafin, K., Land, S., & Oliver, K. (1997). Grounded Practice and the Design of Constructivist Learning Environments. *Educational Technology Research & Development, 45* (3), pp.

Hannafin, M.J., & Land, S.M. (1997). The foundations and assumptions of technology-enhanced student-centered learning environments. *Instructional Science.*

Harel, I., & Papert, S. (1991). Software design as a learning environment. In I. Harel & S. Papert (Eds.), *Constructionism* (pp. 41-84). Norwood, NJ: Ablex.

Hawkins, J., & Pea, R. (1987). Tools for bridging the cultures of everyday and scientific thinking. *Journal of Research in Science Teaching, 24* (4), 291-307.

Hill, J.R., & Hannafin, M.J. (1997). Cognitive strategies and learning from the World Wide Web. *Educational Technology Research & Development, 45* (4), 37-64.

Holland, J., Holyoak, K., Nisbett, R., & Thargard. (1986). *Induction: Processes of inference, learning, and discovery.* Cambridge, MA: MIT Press.

Jonassen, D. (1991). Objectivism versus constructivism: Do we need a new philosophical paradigm? *Educational Technology Research and Development, 39,* 5-14.

Kardash, C.M., & Scholes, R.J. (1995). Effects of preexisting beliefs and repeated readings on belief change, comprehension, and recall of persuasive text. *Contemporary Educational Psychology, 20,* 201-221.

Karmiloff-Smith, A., & Inhelder, B. (1975). "If you want to get ahead, get a theory." *Cognition, 3* (3), 195-212.

Land, S.M., & Hannafin, M.J. (1996). A conceptual framework for the development of theories-in-action with open-ended learning environments. *Educational Technology Research & Development, 44* (3), pp. 37-53.

Land, S.M., & Hannafin, M.J. (1997). Patterns of understanding with open-ended learning environments: A qualitative study. *Educational Technology Research & Development, 45*(2), 47-73.

Linn, M. C., Bell, P. & Hsi, S. (in press). Lifelong science learning on the Internet: The Knowledge Integration Environment. *Interactive Learning Environments.*

Mayer, R.E. (1984). Aids to text comprehension. *Educational Psychologist, 19,* 30-42.

Mayer, R.E. (1989). Models for understanding. *Review of Educational Research, 59,* 43-64.

McCaslin, M., & Good, T. (1992). Compliant cognition: The misalliance of management and instructional goals in current school reform. *Educational Researcher, 21* (3), 4-17.

Microworlds Project Builder (Version 1.02) [Computer program]. (1993). Highgate Springs, VT: Logo Computer Systems, Inc.

Perkins, D.N. (1985). The fingertip effect: How information processing technology shapes thinking. *Educational Researcher, 14,* 11-17.

Perkins, D., & Simmons, R. (1988). Patterns of misunderstanding: An integrative model for science, math, and programming. *Review of Educational Research, 58,* 303-326.

Petre, M. (1995). Readership skills and graphical programming. *Communications of the ACM, 38* (6), 33-43.

Piaget, J. (1976). *The grasp of consciousness.* Cambridge, MA: Harvard University Press.

Rieber, L. (1992). Computer-based microworlds: A bridge between constructivism and direct instruction. *Educational Technology Research & Development, 40* (1), 93-106.

Rieber, L. (1995). A historical view of visualization in human cognition. *Educational Technology Research & Development, 43* (1), 45-56.

Roth, W.M., & Roychoudhury, A. (1993). The development of science process skills in authentic contexts. *Journal of Research in Science Teaching, 30* (2), 127-152.

Salomon, G., Globerson, T., & Guterman, E. (1989). The computer as a zone of proximal development: Internalizing reading-related metacognitions from a reading partner. *Journal of Educational Psychology, 81* (4), 620-627.

Salomon, G., Perkins, D., & Globerson, T. (1991). Partners in cognition: Extending human intelligence with intelligent technologies. *Educational Researcher, April,* 2-8.

Scardamalia, M., Bereiter, C., McLean, R., Swallow, J., & Woodruff, E. (1989). Computer-supported intentional learning environments. *Journal of Educational Computing Research, 5,* 51-68.

Spiro, R., Feltovich, P., Jacobson, M., & Coulson, R. (1991). Cognitive flexibility, constructivism, and hypertext: Random access instruction for advanced knowledge acquisition in ill-structured domains. *Educational Technology, 31* (5), 24-33.

Savery, J. R., & Duffy, T.M. (1996). Problem-based learning: An instructional model and its constructivist framework. In B.G. Wilson (Ed.), *Constructivist learning environments: Case studies in instructional design.* (pp. 135-150). Englewood Cliffs, NJ: Educational Technology Publications.

Schank, R., & Cleave, J. (1995). Natural learning, natural teaching: Changing human memory. In H. Morowitz and J. Singer, (Eds.), *The mind, the brain, and complex adaptive systems.* (pp. 175-202). Reading, MA: Addison-Wesley.

Schön , D.A. (1983). *The reflective practitioner: How professionals think in action.* New York: Basic Books.

Vosniadou, S. (1992). Knowledge acquisition and conceptual change. *Applied Psychology: An International Review, 41* (4), 347-357.

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

Wallace, R., & Kupperman, J. (1997, April). On-line search in the science classroom: Benefits and possibilities. Paper presented at the 1997 AERA conference. Chicago: IL.

Wilson, D., & Brekke, N. (1994). Mental contamination and mental correction: Unwanted influences on judgments and evaluations. *Psychological Bulletin, 116* (1), 117-142.