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The foundations and assumptions of technology-enhanced student-centered learning environments

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Abstract. Direct instruction approaches, as well as the design processes that support them, have been criticized for failing to reflect contemporary research and theory in teaching, learning, and technology. Learning systems are needed that encourage divergent reasoning, problem solving, and critical thinking. Student-centered learning environments have been touted as a means to support such processes. With the emergence of technology, many barriers to implementing innovative alternatives may be overcome. The purposes of this paper are to review and critically analyze research and theory related to technology-enhanced student-centered learning environments and to identify their foundations and assumptions.

Key words: student-centered learning, learning environments, technology

The pursuit of ideal teaching and learning methods has challenged educators for centuries. Recent emphases in student-centered approaches have revitalized interest in alternative teaching and learning perspectives. The most closely-studied differences have been between "traditional" directed-teaching methods and learner-centered constructivist approaches. Direct methods have been criticized for failing to emphasize practical problem solving and critical thinking (e.g., Brown, Collins, & Duguid, 1989; National Science Teachers' Association, 1993). Some educators have attributed performance deficiencies to teaching approaches that cultivate oversimplified, and often superficial, understanding (Spiro, Feltovich, Jacobson, & Coulson, 1991). Externally-centered instructional methods, according to critics, fail to address the knowledge requirements of a rapidly expanding technological society.

Several perspectives have emerged among designers of learning systems. Many believe that instructional design methodologies, themselves, are not inherently limiting. Limitations in their use, it is argued, result from narrow interpretation rather than shortcomings in the approaches themselves (Reigeluth, 1989). Others advocate extending or adapting conventional design methodologies to better accommodate diverse perspectives and contemporary research and theory (Lebow, 1993; Rieber, 1992). Still others disagree, noting that the assumptions and pedagogy associated with instruction are incompatible with non-objectivist approaches (Cunningham, 1987; Kember & Murphy, 1990). Finally, interest has surfaced in "students as designers," that is, learning environments that support user-centered construction activity (Harel & Papert, 1991; Reigeluth, 1996). Interest in and the need for alternative approaches is apparent; it is not clear, however, how best to support such alternatives.

Student-centered learning environments have been touted as an alternative to externally-directed instruction. While, at face value, the potential of student-centered learning environments is compelling, the logistical problems associated with implementing them are formidable. Recent advances in computer and related technologies, however, have facilitated the management of electronic resources, making student-centered alternatives both possible and feasible. Computer-enhanced learning environments "... promote engagement through student-centered [learning] activities" (Hannafin, 1992, p. 51). Technology-enhanced, student-centered learning environments organize interrelated learning themes into meaningful contexts, often in the form of a problem to be solved or an orienting goal, that bind functionally their features and activities. They provide interactive, complimentary activities that enable individuals to address unique learning interests and needs, study multiple levels of complexity, and deepen understanding. They establish conditions that enrich thinking and learning, and use technology to enable flexible methods through which the processes can be supported.

Many technology-enhanced student-centered learning environments have been developed, ranging from situated, problem-based approaches (e.g., Jasper Woodbury Series, Voyage of the Mimi), to microworlds (e.g., Logo, Project Builder), to specialized manipulation tools (e.g., Geometer's Sketchpad). Research on these environments, while promising, has focused largely on the presumed uniqueness of the approaches. Among constructivists, beliefs about how to promote understanding vary widely (Phillips, 1995). Design guidelines and heuristics have occasionally been offered (e.g., Perkins, 1991; Young, 1993), but they have not stimulated what Glaser (1976) characterized as a "science of design." Consequently, apart from isolated studies, comparatively little understanding of the role of technology in the design of student-centered learning environments has evolved. The purposes of this paper are to provide a brief overview of technology-enhanced, student-centered learning environments, and to identify the foundations and underlying assumptions common across student-centered designs.

The emergence of technology in student-centered learning environments

Interest in environments that immerse individuals in authentic learning experiences, where the meaning of knowledge and skills are realistically embedded, has been long standing. John Dewey (1933, 1938), for example, characterized schools as settings in which students received life-apprenticeships. Piaget (1952) suggested that children innately build and alter understanding through everyday interactions with their environments; the goal of education, in effect, is to provide a stimulating environment to support the child's natural epistemic curiosity. More recently, attempts to situate cognition in authentic learning-performing tasks have become widespread (e.g., Brown, Collins, & Duguid, 1989; Cognition and Technology Group at Vanderbilt, 1991, 1992). Systems are designed not so much to instruct as to provide contexts wherein understanding and insight can be uniquely cultivated.

In a contemporary sense, Papert's (1993b) concept of microworlds as "... incubators for knowledge" (p. 120) reflects the philosophical biases of many computer-enhanced, student-centered learning environments. Microworlds nurture individual learning and understanding rather than teach explicitly (cf. Olson, 1988). They emphasize empowerment through meta-knowledge which individuals invoke and refine while attempting to make sense of their environment. Microworlds employ technologies that enable learners to manipulate complex concepts in tangible, concrete ways. They emphasize the uniqueness of these processes and the need to discover, predict, test, reformulate, and construct personally-relevant meaning (Edwards, 1995).

Similarly, interest has grown in interactive multimedia environments that are student-centered. Such systems provide rich databases, tools, and resources to support self-directed inquiry and information seeking and retrieval, as well as individual decision making (Land & Hannafin, 1996). Understanding is assumed to evolve through the processes of exploring, inquiring, and constructing representations and/or artifacts (see for example, use of the *World Wide Web* (Shotsberger, 1996), *Perseus* (Crane & Mylonas, 1988), and *Intermedia* (Yankelovich et al., 1988)).

Perspectives on the role of technology in student-centered learning have expanded, both conceptually and operationally, during recent years (see for example, APA, 1992). Changes have been reflected in the nature and breadth of experiences made available and in the capacity to support these experiences technologically. Learning systems of enormous power and sophistication have been developed to represent evolving notions of the partnerships among learners, experience, discourse, and knowledge. Student-centered learning systems reflect research and theory ranging from situated, contextual teaching and learning (Brown & Duguid, 1993; Roth & Roychoudhury, 1993) to resource-based models of education (Reigeluth, 1989).

Views about learning

Student-centered learning environments evolved as a result of shifting beliefs and assumptions about the role of the individual in learning. Contemporary designers have been influenced heavily by constructivists who assert that understanding transcends the encoding of literal information and is uniquely constructed (Guba, 1990; Jonassen, 1991; Phillips, 1995). Knowledge must be assimilated; perceptions of value, meaning, and importance must be tentatively derived; existing knowledge must be evaluated concurrently with new knowledge; and understandings must be reconstructed accordingly (Hannafin, Hill, & Land, in press). In effect, student-centered learning environments emphasize constructing personal meaning by relating new knowledge to existing conceptions and understandings; technology promotes access to resources and tools that facilitate construction.

Recently, researchers have examined how learners evolve understanding in technology-rich learning environments. Effective environments support the individual's intentions to derive and solve problems through the use of available resources and tools (Edwards, 1995; Jonassen, 1992). The result is a complex interaction among prior knowledge, perception of events, intents, actions, observations, and reflections attendant to on-going thoughts and actions (Land & Hannafin, 1996). Actions, goals, and processes are initiated as a result of both previous system experiences and intuitive assumptions about the concepts under study. Learning, then, is a dynamic process of "reflection-in-action" where action is used to extend thinking, and reflection is governed by the results of action (Schön, 1983).

Views about teaching

Several efforts, principally in the sciences and mathematics, have demonstrated alternative roles for technology in teaching and learning (see, for example, Cognition and Technology Group at Vanderbilt, 1991, 1992; diSessa & White, 1982; Levin & Waugh, 1987; Roth & Roychoudhury, 1993; Linn & Muilenburg, 1996; Tobin & Dawson, 1992). The focus has often been on developing critical thinking, problem solving, and reasoning skills. The overarching goals are to encourage manipulation rather than simple acquisition, and to root the learning process in concrete experience. These systems, it has been argued, represent fundamentally different views and beliefs about teaching and the nature of learning, not a simple re-hosting of traditional approaches.

The utility of instructional approaches, the means through which traditional teaching and learning assumptions are often operationalized, has been detailed by several theorists who have derived very different inferences (see, for example, Winn, 1993). Gagné & Merrill (1990) noted that instruction must focus on broader, more integrative outcomes than typically assumed, a theme that has become increasingly popular. Merrill, Li, & Jones (1990a, 1990b) cited the closed nature of traditional approaches, absence of guidance for interaction design, and limited adaptation as constraints of traditional models of computer-based learning. They advocated an extension of traditional models to account for the capabilities of emerging technologies. While Merrill and his colleagues advocate changes in the systems used to generate instruction, their underlying assumptions as to the nature of learning remains consistent with objectivist epistemology.

This view has been challenged. Kember & Murphy (1990) suggested that alternative models, rooted in constructivism, encourage meaningful learning and allow for pragmatic design and development. Others have advocated systems that promote diversity of perspective through individual or social knowledge construction rather than uniformity of interpretation. The Language Development and Hypermedia Research Group (1992), for example, proposed "open software" designed to develop multiple perspectives. Similar social construction applications of open, student-centered learning principles have been devised (e.g., Scardamalia et al., 1989; Yankelovich et al., 1988).

Increased interest in student-centered learning has been evident. Yet, the nature of the systems seems, to many, to be more dissimilar than alike. It is important to recognize both similarities and differences among technology-enhanced, student-centered environments.

Technology

Rapid developments in technology have influenced the evolution of student-centered learning environments (Strommen & Lincoln, 1992). Complex information systems can now be designed and accessed for individual purposes with comparative ease (Marchionini, 1988). Emerging information systems, such as the *World Wide Web*, support varied student-centered approaches in a variety of settings (Shotsberger, 1996). Integrated multimedia platforms are now commonplace, providing powerful systems for developing and using highly sophisticated learning environments.

Software innovations have also been prominent. Significant advances in authoring, multimedia development, production tools, simulation software, and expert system shells have been apparent (see for example, Li & Merrill, 1990). Simplified use has increased interest in classroom applications of "learning by designing" (see for example, Harel & Papert, 1991; Pea, 1991; Trollip & Lippert, 1987). Software developments have increased not only the power and versatility of emerging systems, but have made them increasingly friendly and intuitive. Individuals can uniquely define the purposes of technology's uses, and exploit its capabilities to support individual interests and needs.

Despite advances in technology, however, comparatively little impact of any significant scale has been evident. Teaching-learning approaches have often been re-hosted, not re-defined. Technology has been harnessed to accomplish conventional aims, but comparatively few applications have unleashed the potential of either the technologies or learners. Student-centered learning environments represent significant potential for optimizing the capabilities of both technology and learners. Improved understanding of the foundations and assumptions of such systems is needed.

Foundations of technology-enhanced student-centered learning environments

Learning environments are rooted in five foundations: Psychological, pedagogical, technological, cultural, and pragmatic. Direct instruction environments typically draw upon foundations that are consistent with objectivist, designer-centered perspective. Student-centered learning environments' foundations, on the other hand, reflect a more user-centered view about the nature of knowledge and the role of the learner. Both are rooted in psychological foundations, but the approaches differ.

Psychological

All learning environments, explicitly or tacitly, reflect underlying beliefs about how knowledge is acquired and used. Psychological foundations reflect views about how individuals acquire, organize, and deploy knowledge and skill. Psychological foundations are subsequently operationalized through various design frameworks, activities, and strategies, which reflect beliefs about how individuals think, learn, understand, and act.

Historically, learning environments were rooted psychologically in behaviorism, with stimulus-response-reinforcement associationism as the core explanatory learning paradigm. Relevant information was presented, practice elicited, and specific, contiguous feedback provided (Hannafin et al., 1996; Hannafin & Rieber, 1989a). Directed drill and practice programs, as well as convergent tutorial programs, are consistent with behavioral foundations.

Much of the latter-day psychological tradition of learning environments is derived from cognitive psychology (APA, 1992). Cognitive research focused on the processes associated with learning, such as selecting and processing limitations and capacities, organizing stimuli into meaningful units, integrating new with existing knowledge, and retrieving and using knowledge and skills (Hooper & Hannafin, 1991). Information-processing theory led to fundamental shifts from the external, behavioral conditions of learning to the underlying processes involved in selecting, encoding, and retrieving. Gagné (1985), for example, used information-processing theory as a cornerstone of his conditions – internal and external – of learning. Seminal concepts have been derived related to the influence of limited short-term memory capacity (Klatzky, 1975; Miller, 1956), depth of processing (Craik & Lockhart, 1972; Craik & Tulving, 1975), elaboration (Anderson & Reder, 1979), meaningfulness (Mayer, 1984; 1989), and schemata (Anderson, Spiro, & Anderson, 1978). Likewise, individual variables, such as metacognition and perceived self-efficacy (Salomon, 1979), have enhanced present-day understanding of the psychological make-up of the learner. Cognitive research has been instrumental in shaping views of learning as an internally-mediated process.

Social cognitivists have focused on the relationship between context and knowledge, emphasizing the socially-mediated aspects of learning (see, for example, Belmont, 1989; Brown, Collins & Duguid, 1989; Lave & Wenger, 1991) as well as the influence of social context on understanding (Young & McNeese, 1995). Knowledge, and the contexts in which it derives meaning, are considered to be inextricably related. Conversely, knowledge isolated from contexts is of little productive value and is likely to be "inert" (Whitehead, 1929). The emphasis on contextually-rich, authentic experience rather than decontextualized information is a direct outgrowth of these perspectives.

Contemporary interpretations of constructivism evolved from the contributions of Piaget (1952) and Vygotsky (1978), among others. Knowledge, according to constructivists, is not fixed or external; it is individually constructed. Thus, understanding is derived through experience. Ideally, student-centered learning environments emphasize concrete experiences that serve as catalysts for constructing individual meaning. This premise is central to the design of many contemporary learning systems.

Technology-enhanced, student-centered learning environments manifest diverse psychological foundations. For instance, in the *Jasper Woodbury Series* (Cognition and Technology Group at Vanderbilt, 1992), situated learning is the conceptual foundation for embedding knowledge and skills into a practical, authentic context. Microworlds often draw upon concepts of conceptual development and mental models to support building and revising of ongoing beliefs (Edwards, 1995; Rieber, 1992; Twigger et al., 1991). Other programs use constructivist perspectives to develop critical thinking and science process skills (Roth & Roychoudhury, 1993; Tobin & Dawson, 1992). Despite apparent variations, however, common psychological foundations are manifested in the roles of technology in supporting activities, features, and opportunities to support student-initiated, student-directed understanding.

A host of influences has been extrapolated from psychological research and theory, including those garnered from traditions as well as those based in contemporary perspectives. In comparatively few cases, the psychological foundations of the learning system have been clearly identified (see, for example, Cognition and Technology Group at Vanderbilt, 1992; Twigger et al., 1991). Learning systems need to reflect, and be consistent with, the underlying psychological model upon which they are based. Student-centered learning environments emphasize learners as constructors of knowledge, the importance of context in understanding, and the essential nature of experience in learning.

Pedagogical

Pedagogical influences focus on the activities, methods, and structures of the learning environment; pedagogical foundations emphasize how an environment is designed and its affordances are made available. In concert with an underlying psychological model, they provide the basis for the methods and strategies employed and the ways in which to-be-learned content is organized.

Pedagogical foundations represent the operational bases for the different methods and activities generated using varied design models (see, for example, Hannafin & Rieber, 1989b). Direct instruction approaches frequently emphasize instructional strategies such as hierarchical structure of to-be-learned content, objective-relevant questioning, feedback, and assessment of progress toward mastery (see for example, Dick & Carey, 1990; Gagné, Briggs, & Wager, 1988). Typically, these issues concern the influence of lesson organization and sequence and mathemagenic activities to address known, externally-defined performance requirements.

In contrast, generative activities such as learning strategy training (Derry & Murphy, 1986) and learner choice and control (Chung & Reigeluth, 1992) are designed to capitalize on the unique cognitive capabilities of individual learners. While external structure tends to influence the success of such strategies, they are designed to empower the learner with methods that are widely applicable across diverse learning tasks.

Clearly, varied assumptions yield different strategies and frameworks. Objectivists tend to stress the hierarchical nature of knowledge, and advocate "bottom-up," externally-structured approaches to learning. Operationally, concepts are presented according to stated objectives, mathemagenic strategies are embedded to ensure the attainment of the objectives, intended learning is assessed, and alternatives are invoked (e.g., repeat, recast, or review background material) if needed. In contrast, constructivist designers tend to emphasize exploration among related resources and concrete manipulation (see, for example, Perkins, 1991). In each case, the pedagogical options reflect distinctly different underlying assumptions, and draw upon different pedagogical foundations.

Technology-enhanced, student-centered learning environments establish contexts that promote sampling, discovering, manipulating, and investigating. The individual must reason before acting, assess what needs to be understood, and identify and execute methods believed helpful. The *Science Vision Series*, for example, uses brief orienting scenarios to describe problems confronting a student team (Tobin & Dawson, 1992). The problems are often systemic in nature, focusing on topics such as river pollution. Using technological tools, students navigate, reference on-line resources, conduct experiments, and collect data in their quest for a solution. They need to reason before acting, assess their needs, identify and select methods believed helpful, and reflect on the information selected, encountered, generated, or constructed (Land & Hannafin, in press).

Technology-enhanced, student-centered learning environments create contexts within which knowledge and skill are authentically anchored, and provide a range of tools and resources with which to navigate and manipulate (Hannafin, Hall, Land, & Hill, 1994). They afford opportunities to seek rather than to comply, to experiment rather than to accept, to evaluate rather than to accumulate, and to interpret rather than to adopt. Yet, they may also draw upon related constructs, such as generative strategies and elaboration. Pedagogical foundations, therefore, are not confined to methods derived from constructivism, but represent a synthesis of research and theory which establishes contexts, resources, and tools to promote learning.

Technological

Taken independently, technological capabilities suggest what is *possible* through advances in technology, not necessarily what is required or desired. When considered with the other foundations, technological foundations represent how the capabilities and limitations of available technologies can be optimized.

Technologies can be distinguished by the operations they support and the symbol systems they employ. Computers, for instance, utilize printed text, graphics, sound effects, and animation. They also utilize various aural, visual, and tactile modalities and options for digital, analog, still, or synthesized media. Yet, computers also offer capabilities such as data processing and management that often are unavailable with print or other type of media. The options can be integrated and manipulated via sophisticated technologies capable of complex processing and presentation. Technological capabilities constrain or enhance the types of learner-system transactions that are possible.

Technological foundations influence the design of learning systems by establishing the toolkit available to both the designer and the learner (see, for example, Bagley & Hunter, 1992). Computers can monitor responses, provide individualized feedback about choices, and maintain records of performance. However, these capabilities exist independently of particular design assumptions or decisions; design decisions regulate how, or if, technological capabilities will be utilized.

Technological capabilities dictate not how much learner control is supported, but how much is *possible*. They determine not what *should* be, but what *could* be. Furthermore, technological capabilities can be exploited as tools (e.g., to select text for electronic notebooks, perform calculations, request additional help) to manipulate objects. Finally, technological capabilities can be used to personalize instruction or to advise learners about useful processes or information at appropriate times.

Technology-enhanced, student-centered learning environments often facilitate understanding of abstract concepts via concrete experience. For instance, a thermodynamics environment allows learners to collect real-time temperatures of various objects, noting changes as they are displayed graphically (Lewis, Stern, & Linn, 1993). Learners vary parameters such as initial temperature, surface area, and insulation material. Technological tools, in this instance, redefine the experiences available to learners and the cognitive requirements of a learning task.

Technological capabilities may also promote heretofore untested designs and strategies. They can redefine what is possible or feasible and stimulate new perspectives on the teaching-learning process. The challenge for designers is to capitalize on the capabilities of emerging technologies based upon existing designs, while generating new designs rooted in emerging psychological and pedagogical research and theory. For such shifts to occur, foundations related to teaching, learning and technology, and the features related to those foundations, need to be aligned.

Cultural

Cultural foundations reflect prevailing beliefs about education, the values of a culture, and the roles of individuals in society. The American school system, for example, initially accommodated agricultural calendars in predominantly rural areas. The need for vocational and technical training evolved due to industrialization, with changes in structured “factory models” of schooling (Reigeluth, 1989). Likewise, the USSR’s launching of Sputnik in 1960 catalyzed the United States to a national agenda to improve science and mathematics teaching and learning. More recently, the need to meet the knowledge requirements of our rapidly expanding technological society has emerged.

Computers are increasingly prevalent in classrooms and educational software is widely available; schools mirror the values and priorities of an increasingly technological society.

Cultural foundations influence the design of learning systems by reflecting social mores and values concerning the nature and role of education. Educational systems in industrialized Asia, for example, place exceptional emphasis on competition and the acquisition of rote knowledge. They provide intensive classroom instruction, administer highly competitive national tests to determine eligibility for very select colleges and universities, and require significant commitments by families to ensure the futures of children. The educational systems are microcosms of the highly competitive and successful industrialized societies which evolved during the latter half of the 20th century. Many European nations, on the other hand, place substantially less emphasis on competition and rote learning in favor of reflection and self-study. Evolution in a given culture's educational priorities occur because of the real (or perceived) need to increase, decrease, or shift focus based upon prevailing attitudes, beliefs, and societal mores.

The same can be said for individual school districts, schools, classrooms, teachers, instructional units, and classroom modules. Each reflects, in a very real sense, the philosophy of its parent organization (e.g., school boards, teachers). This is important in any learning system, but it is of special relevance in the design of learning environments. The culture affecting learning environments can be traced to groups such as scientists, engineers, corporations, and advocacy groups. Vocational education, for example, has been influenced heavily by both projections about future workforce needs and perceptions of the readiness of current students. Likewise, many scientists have advocated increased attention to reasoning, critical thinking, and problem solving – that is, learning science as a scientist rather than a body of formal knowledge. Consequently, technology-enhanced, student-centered learning environments have evolved to support philosophical shifts in the nature of teaching, learning, and technology.

Pragmatic

Each setting has unique situational constraints that affect the design of learning systems. Issues such as run-time requirements, hardware/software availability and compatibility, and financial concerns establish significant constraints. Pragmatic foundations bridge the gap between theory and reality. They emphasize the practical reasons a particular approach can or cannot be used in a given learning environment.

Pragmatics might also dictate that learning environments blend aspects of varied pedagogical models. For instance, the *Space Shuttle Commander* environment utilizes both manipulation strategies and direct instruction in recognition of everyday classroom teaching-learning constraints (Rieber, 1992). Similarly, the Cognition and Technology Group at Vanderbilt (1992) outlined several alternative implementation strategies to accompany the *Jasper* series. The strategies range from a "basics first" to open problem-solving approaches. Such systems are designed to promote usage in ways that accommodate situational biases and constraints.

In a very real sense, pragmatic foundations dictate what *can be* in a learning environment, accounting for both human and technological assets and limitations as well as situational factors. However, not all perceived constraints are real. Some concerns reflect limited perspectives rather than legitimate constraints. As technological, psychological, and pedagogical research and theory continues to advance, designers must develop systems that accommodate the *real* constraints of the learning environment while overcoming those rooted in narrowness of their perspectives.

An integrated view

Though presented in isolation, the foundations are functionally integrated in learning system designs. The various manners in which they are manifested reflect fundamentally different assumptions about the nature of teaching, learning, knowing, and understanding. As illustrated conceptually in Figure 1, each foundation *should* interact to some degree with all others, indicating mutual interdependence. As foundations become increasingly or decreasingly interdependent, the intersection increases or decreases accordingly. The more complete the coincidence, the better integrated the foundations; the better integrated the foundations, the greater the probability of success in the setting for which the learning environment is designed. In practice, the larger the coincidence among foundations, the better aligned the learning system's underlying psychological, pedagogical, technological, cultural, and pragmatic factors.

Complete alignment is, however, relatively rare. Environments rooted primarily in a single foundation (e.g., fascination with the use of the Internet in the classroom) may be limited if they fail to reflect coincidence among important foundations. Figures 2a–2d reflect a familiar problem encountered in technology-enhanced, student-centered learning environments. Figures 2a–2b illustrate an environment well-aligned in psychological, pedagogical, and technological foundations. The psychological framework is consistent with constructivist-situated cognition perspectives, emphasizing powerful, authentic learning contexts and student-centeredness. The pedagogical strategies are largely consistent with these foundations, providing problem statements and framing, and a variety of methods such angling and scaffolding.

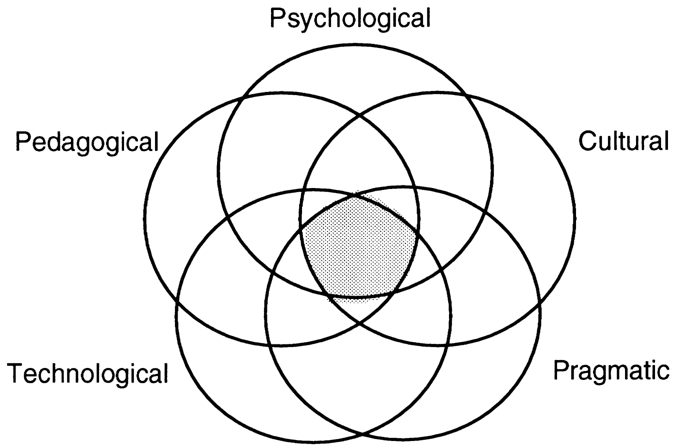

Figure 1. A conceptual representation of a balanced, integrated technology-enhanced student-centered learning environment.

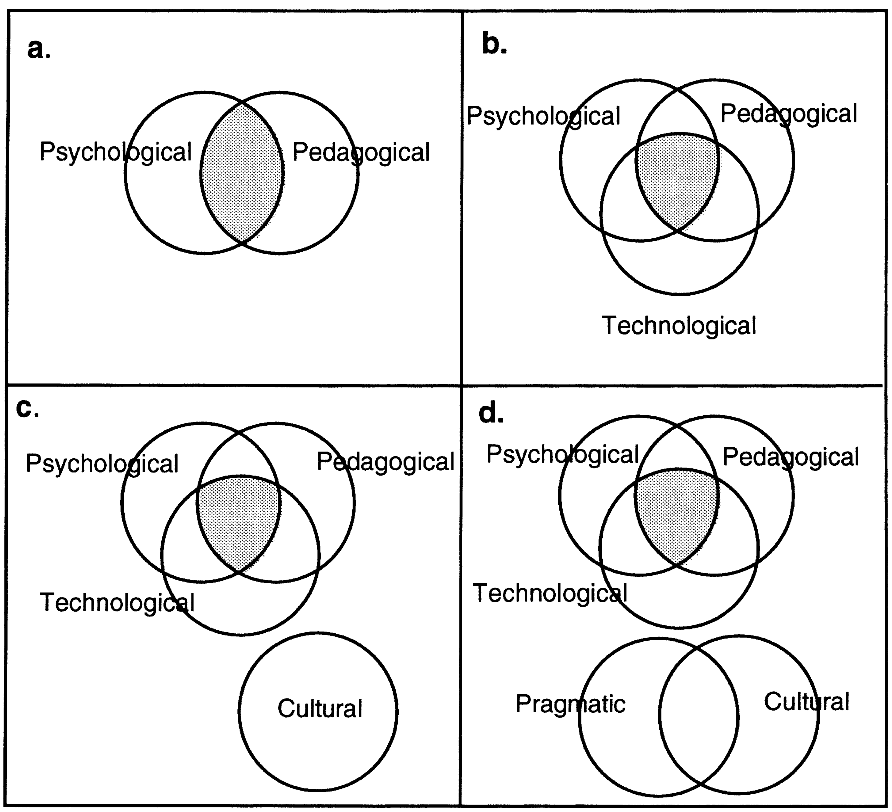

Figure 2a–2d. A conceptual representation of a partially integrated technology-enhanced, student-centered learning environment.

Technological tools for manipulation and a host of highly indexed multimedia resources are provided, perhaps via the World-Wide Web, again in ways that support the environment's pedagogical and psychological foundations.

When cultural influences are considered, however, substantial inconsistencies are indicated with the beliefs and priorities of those implementing formal education (workplace environment, school, classroom, etc.) (see Figure 2c). In this case, the school, teachers, and community may have adopted a basics-first approach, and employed a mastery-based curriculum. The given culture values direct, structured teaching and learning features not consistent with the preceding foundations. Figure 2d suggests that pragmatic factors also mitigate against the student-centered approach (though pragmatic and cultural foundations are highly aligned). Perhaps the school day is not amenable to needed re-scheduling, financial resources have been exhausted, or there is a limited capacity for additional activities in an already busy school day. This is commonplace where technology resources are insufficient to support sophisticated technologies (e.g., limited access to high-speed access to the World-Wide Web, few computers). The available resources have been dedicated to hiring personnel and purchasing supplementary materials to reinforce and focus teaching and learning. An innovative learning system has been developed, but it simply does not fit the environment for which it was intended.

Assumptions of technology-enhanced student-centered learning environments

In theory, all learning environments draw upon each root foundation. The conceptual overlap among foundations may be extensive, but still reflect fundamentally different requirements. As noted previously, an environment rooted in objectivist epistemology, such as those in highly focused technical training, may involve strong alignment among behavioral theory, mathemagenic learning strategies, and highly directed use of technology features. An open learning system may yield the same degree of conceptual alignment, but draw upon different subsets of the foundations (e.g., learning as construction, manipulation tools, and navigation browsers).

Underlying assumptions determine, in unambiguous ways, how (or if) the foundations are connected. The importance of underlying assumptions, therefore, cannot be overstated: they dictate how foundations are operationalized in any environment. As the assumptions vary, the foundations, and hence the features and methods, of the learning environment change accordingly.

Technology-enhanced student-centered learning environments comprise many forms, often with few apparent similarities. The efforts are often very dissimilar in functions, goals, and features, making it difficult to identify overarching design principles. Despite such variations, common assumptions are manifested either explicitly or implicitly within the environment. Table 1 summarizes the assumptions, with supporting examples, functions, and research.

Instruction, traditionally operationalized, is too narrow to support varied learning requirements

Direct instruction is inherently neither good nor bad; it is very effective in promoting particular kinds of learning and problematic for others (Hannafin, 1992). Dick (1991) described instruction as "... an educational intervention that is driven by specific outcome objectives ... and assessments that determine if the desired changes in behavior [learning] have occurred" (p. 44). To the extent that learning or performance outcomes are explicitly known, explicit procedures must be learned, or efficiency in acquisition is valued, direct instruction provides a powerful methodology. Instruction, and the processes of traditional design, emphasize prescribed instructional objectives, congruence among objectives, methods, and performance standards, hierarchical analysis of to-be-learned lesson content, and convergent, externally-prescribed instructional activities. "Bottom-up" approaches inherently emphasize the importance of formal prerequisite knowledge and specific content outcomes. Instruction is directive in nature, tending to be concerned more with *what* performance is elicited than *how* it is derived (Trollip & Lippert, 1987).

Much of what should be learned, however, need not be taught directly; indeed, some *cannot* be taught directly. The emphasis on the hierarchical nature of prerequisites, for example, may limit the potential for novice learners to engage complex, formal ideas. Papert (1993b), for example, noted that even very young children can encounter advanced ideas such as differential equations and Newtonian physics through use of a transitional, enabling system that exists in the child's world. Everyday phenomena and experiences provide concrete instances of otherwise abstract concepts. The learning potential achieved through collaboration between the environment and the learner is represented theoretically as Vygotsky's (1978) "zone of proximal development." Within this zone, the learner interacts in ways not possible independent of the environment (Belmont, 1989; Salomon, Globerson, & Guterman, 1989). Others have noted that children's learning capabilities have been underestimated (Novak & Musonda, 1991; Roth & Roychoudhury, 1993). Understanding, it is argued, is neither inherently hierarchical nor the product of incremental teaching methods, but a natural consequence of curiosity, experience, reflection, insight, and personal construction.

Table 1. Examples, functions, and supporting research for the assumptions of student-centered learning environments.

Assumption	Examples of methods & Activities	Functions	Associated research & theory
Instruction, traditionally operationalized, is too narrow to support varied learning requirements	• Basics first vs. initial exploration of complex concepts	• Allows learners to “make sense” out of what they know; engages them in complex ideas	• Hierarchical, “bottom-up” approaches (Dick & Carey, 1985) vs. anchored instruction (CTGV, 1990)
	• Decontextualized instruction vs. contextualized learning	• Supports meta-knowledge about problem solving; addresses complex thinking vs. rote memory & disassociation problem	• Strategy training (Derry & Murphy, 1986) vs. cognitive apprenticeships (Brown, Collins, & Duguid, 1989)
	• Direct instruction vs. exploration and manipulation	• Leads to deeper understandings and personal model building and refinement	• External conditions of learning (Gagné, 1985) vs. model building and reconstruction (Piaget, 1986; Papert, 1993b)
	• Presentation of facts vs. cultivation of individual sense-making	• Increase meaningful understandings and relationships with phenomena	• Behaviorism vs. mathetics (Papert, 1993a; 1993b) and reflexivity (Cunningham, 1987)
Understanding is best supported when cognitive processes are augmented, not supplanted, by technology	• Technology-enhanced automation of selected processes	• Allows novices to get familiar with complex notions without excessive cognitive load; supports conceptual manipulation	• Distributed intelligence (Pea, 1993); Effects “of” technology (Salomon, Perkins & Globerson, 1991)
	• Learner-generated predictions, model building, & testing	• Facilitates building and evolving of theories or beliefs	• Mental model building (Mayer, 1989; Rieber, 1992); theories-in-action (Karmiloff-Smith & Inhelder, 1975)
	• Socially, materially, & technologically rich environments	• Leads to deeper understanding; understanding surpasses what could be achieved without support	• Phenomenaria (Perkins, 1991); cognitive apprenticeships (Brown, Collins & Duguid, 1989)
	• Cognitive tools	• Empowers learners to extend thinking and process higher-order concepts.	• Cognitive tools (Kozma, 1987); mindfulness (Salomon, 1986).

Table 1. Continued.

Assumption	Examples of methods & Activities	Functions	Associated research & theory
Learning environments need to support the underlying cognitive processes, not solely products of understanding	• Support individual sense-making	• Increases meaningful learning and connections among ideas	• Mathetics (Papert, 1993a; 1993b)
	• Process-oriented resources	• Promotes cognitive engagement and development	• Process learning (Hannafin & Grumelli, 1993); phenomenaria (Perkins, 1991)
	• Support making cognitive/ metacognitive processes overt	• Supports learning of self-regulation skills as learners become aware of strategies; Supports development of meta-knowledge	• metacognition: covert processes made overt (Scardamalia et. al, 1989); executive control (Perkins, 1993)
Understanding evolves continuously	• Learner-generated predictions, model building, testing, and revising	• Supports learners in formulating intuitions or mental models	• Knowledge reconstruction; assimilation-accommodation (Land & Hannafin, 1996)
	• Experiments, manipulations, simulations and microworlds	• Understanding is refined through experience	• "incubators of knowledge" (Papert, 1993a; 1993b; Edwards, 1995)
	• Concept mapping, generative learning strategies	• Addresses compliance vs. evaluation issue	• Intentional learning (Scardamalia et. al, 1989); model building/enhancing (Mayer,1989)

Table 1. Continued.

Assumption	Examples of methods & Activities	Functions	Associated research & theory
Individuals must assume greater responsibility for their learning	• Encourage awareness of learners' personal knowledge construction process	• Encourages a richer understanding of beliefs; gives learners control over learning process	• Reflexivity (Cunningham, 1987); mathetics (Papert, 1993a; 1993b)
	• Emphasize making metacognition overt and deployment/use of metacognitive skills	• Supports learning of self-regulation skills as learners become aware of strategies	• Strategy training (Derry & Murphy, 1986); intentional learning (Scardamalia et. al, 1989)
	• Emphasize construction of products to represent understanding (e.g., programming and multimedia environments, etc.)	• Supports active learning and individual construction of knowledge; more motivating than being passive recipient	• Constructionism (Harel & Papert, 1991)
Learners make, or can be guided to make, effective choices	• Expand finite set of variables; reduce or expand complexities adaptively	• Supports development of learner's "need to know" more information (self regulation)	• Variable stepping (Rieber, 1992)
	• Establish problem to solve and provide supporting resources as "need to know"	• Establishes an "anchor" upon which further complexities can be added	• Anchoring (CTGV, 1992); problem-based environments (Tobin & Dawson, 1992)
	• Learner-generated predictions, model building, & testing; experimentation with immediate feedback about results (microworlds; simulations)	• Learners see errors as a cue for further information in the natural process of working towards a goal	• model building in microworlds (Edwards, 1995; Rieber, 1992)
	• Expert commentaries/feedback	• Learners can check their own ideas with that of an expert (as a part of self-monitoring)	• Amplification of relevance/expert processes for self-monitoring of learning (Spiro et. al, 1991; Thurber et al., 1991)

Table 1. Continued.

Assumption	Examples of methods & Activities	Functions	Associated research & theory
Learners perform best when varied/multiple representations are supported	• Activities supporting multiple knowledge representations and perspectives	• Diminishes over-simplification problem; supports flexible, decontextualized knowledge that can be applied outside of a particular context	• Reflexivity (Language Development and Hypermedia Research Group, 1992); Cognitive Flexibility (Spiro et. al, 1991)
	• Activities supporting varied contexts/cases	• Supports more complex and multi-faceted understanding	• Analogs and extensions (CTGV, 1992); Criss-crossed landscape (Spiro et al., 1991)
	• Activities supporting multiple and varied purposes of knowledge	• Addresses complex learning goals issue	• Constructionism (Harel & Papert, 1991)
Knowledge is most meaningful when rooted in relevant, scaffolded contexts	• Situate learning in context of a problem to be solved; Embed data/supporting resources into problem solving scenario	• De-emphasizes misconceptions and passivity due to disassociated learning	• Anchoring (CTGV, 1992); Situated knowledge (Brown, Collins & Duguid, 1989)
	• Simulate the natural, situated process of learning	• Orients learners to interrelatedness of knowledge; learners use knowledge as a "tool"	• Everyday cognition (Lave & Wenger, 1991)
	• Root learning in concrete contexts	• "Inert" knowledge problem is addressed	• Concrete experiences (Wilensky, 1991)
Understanding is most relevant when rooted in personal experience	• Technologies or environments for making abstract notions concretely accessible	• Normally abstract notions can be experienced, manipulated, scrutinized	• Concrete manipulation (Edwards, 1995; Papert, 1993a; 1993b; Rieber, 1992)
	• Provide multiple experiences for exploring concepts, and building connections	• Richer understanding develops from learning from experience	• Phenomenaria (Perkins, 1991); concrete experiences (Wilensky, 1991); affordances (Pea, 1993)

Table 1. Continued.

Assumption	Examples of methods & Activities	Functions	Associated research & theory
Reality is personally constructed via interpretation and negotiation	• Theory building/enhancing	• Learners formulate and modify initial understanding	• Knowledge reconstructing (Piaget, 1952); theory development (Land & Hannafin, 1996)
	• Support natural consequences of experimentation (i.e., errors)	• Errors are useful as data for refining understanding; lead to persistence in the face of problems.	• Model/intuition building (Papert, 1993a)
Understanding requires time	• Model building and testing	• Cultivate rather than provide understanding	• Microworlds as "incubators for knowledge" (Papert, 1993a)
	• Immerse learners in problems – provide experiences for extended investigation and concept manipulation	• Deeper understanding through "getting to know" phenomena; formulate and develop personal understanding and decisions	• Generative models and environments (Land & Hannafin, 1996; Linn & Muilenburg, 1996; Papert, 1993a; 1993b)

Others have expressed concern regarding the limited capacity of traditional methods to support higher-order, complex thinking (Kember & Murphy, 1990; Papert, 1993a, 1993b). Indeed, some have argued that traditional instruction may engender rigid, oversimplified, knowledge which hinders subsequent learning (Spiro & Jengh, 1990). Highly structured, algorithmic approaches work well for teaching information and skills that are compatible with behavioral and information processing models about learning, but fail to address the complex linkages required for thinking critically and solving problems – key components of contemporary theory (see Bereiter, 1991).

In technology-enhanced student-centered learning environments, a deeper understanding of cognitive requirements and associated learning tasks is necessary (Hannafin, 1989). These environments focus on cultivating problem-solving skills in authentic contexts, promoting flexible knowledge and thinking skills (Spiro et al., 1991), as well as understanding of multiple perspectives (Language Development and Hypermedia Research Group, 1992). Learning is best achieved through extended investigation and experience with phenomena under study. These experiences may be confined to a fixed set of parameters (e.g., microworlds) or be open-ended and constructed by the learner (e.g., programming endeavors, open software).

The goal, then, is to bring learners into contact with richly supported experiences, wherein they can deploy diverse, personal knowledge and tools with which to think. Learners are not only at the center of the environment; they are integral to it. Universal outcomes, activities, and assessments often cannot be established a-priori, but must be derived through the efforts of individuals. Student-centered learning environments afford opportunities, but do not impose explicit conditions, for learning.

Understanding is best supported when cognitive processes are augmented, not supplanted, by technology

The unique potential of the learning environment is realized in the extent to which it supports or alters cognitive processes. A successful environment encourages learners to use its resources and tools to process more deeply and extend thinking (Jonassen, 1996; Jonassen & Reeves, 1996; Kozma, 1987). Learners use system features to derive problems, vary solutions, and expand the boundaries of their understanding. On the other hand, environments may supplant important cognitive processing by assuming the processing requirements of integral operations. Additionally, while tools or resources may *afford* an opportunity for cognitive processing, they may not be used "mindfully" (Salomon, 1986) by the learner to extend thinking or understanding.

Salomon, Perkins, & Globerson (1991) differentiate cognitive effects *with* and effects *of* technology. Effects *with* technology comprise intellectual endeavors that occur only as a result of the learner-technology partnership. Technology, in effect, supports individuals by performing complex tasks such as generating answers via a spreadsheet. In this case, technology provides surrogate intelligence which can be used to accomplish tasks not possible individually. Effects *of* technology yield cognitive "residues" as a result of the learner-technology partnership, which changes the way learners think or enhances their understanding. By eliminating non-essential computational requirements, for example, learners can predict the effects of varying values for one or more spreadsheet variable, test their predictions, and revise their understanding accordingly. Cognitive resources can be re-directed, allowing the learner to think in ways not generally possible in the absence of the supporting tools. In both situations, learners are typically incapable of generating answers without considerable effort; in the latter case, however, the partnership does more than provide an answer – it provides an incubator for thinking which deepens understanding of the underlying processes.

Learning environments need to support underlying cognitive processes, not solely the products, of understanding

Gagné (1985) has been instrumental in establishing the interdependence between thought and action, emphasizing internal and external conditions for given learning outcomes. According to Gagné, once the internal and external conditions necessary for learning have been identified (i.e., defined knowledge, skills, or attitudes), activities can be structured to induce the required processes. The engineering of external conditions is believed to activate the internal processes needed for effective learning.

Many, however, have challenged the separation of content and process (see, for example, Brown, 1985; Brown, Collins, & Duguid, 1989; Piaget, 1952). The separation simplifies the task of designing a learning system, but often fails to induce important processes. When problem-solving skills are broken down and taught via directed learning approaches, personal insight and understanding of the problem-solving *process* itself often fails to develop (Hannafin & Grumelli, 1993).

Student-centered learning environments utilize process-oriented resources – activities that promote cognitive engagement and knowledge reconstruction. *CSILE*, for example, employs computer technology to facilitate the transformation of covert cognitive processes into overt procedures and artifacts (Scardamalia et al., 1989). *CSILE* allows learners to generate connections between new and existing knowledge and to continuously reconstruct understanding. Once overt, learners become increasingly conscious of the processes and adapt their thinking accordingly.

Technology-enhanced student-centered learning environments emphasize processes to a greater extent than do traditional approaches. They support decision-making, problem-solving, manipulating, interpreting, hypothesizing, and experimenting (Roth & Roychoudhury, 1993). Papert (1993a, 1993b) coined the term “mathetics” to describe the processes and stages invoked by individuals in their quest to know or understand. Individuals, as the principle arbiters of their learning processes, evolve unique sense-making methods to interpret their environment. To support and cultivate mathetics, learners need to be empowered through their own strategies or executive functions, not forced to adapt their own methods to accommodate, or supplant their methods with, those provided externally (Perkins, 1993).

Understanding evolves continuously

Objectivists assert that knowledge is an external entity that, once identified, can be organized optimally and disseminated to learners (see, for example, Dick & Carey, 1990; Gagné, Briggs, & Wager, 1988). These beliefs contrast with constructivist views of knowledge and understanding, where learning is a complex, dynamic process through which understanding is continuously facilitated (Hannafin, 1995). Even young children formulate models, though unsophisticated or naive, of their world (Piaget, 1952).

Understanding involves continually modifying, updating, and assimilating new with existing knowledge. It requires evaluation, not simply accumulation. Understanding results from the testing of theories-in-action, and the efforts of learners to reconcile their beliefs in the face of ever-changing experience (Karmiloff-Smith & Inhelder, 1975). Thus, “telling” correct answers or procedures may short-circuit learning, since learners often fail to identify, examine critically, develop, or evaluate their intuitive notions about the world. Intuitive theories-in-action have proven very resistant to change – even when tools and resources for revising naive understanding are available and deployed (Land & Hannafin, in press). Learners accept as valid the accounts and explanations of teachers and textbooks, becoming compliant rather than evaluative in their thinking processes (McCaslin & Good, 1992).

Student-centered learning environments capitalize on the dynamic nature of knowledge by providing means for developing, testing, and refining personal theories. Rather than an end-product of instruction, original understanding exists as an “anchor” from which subsequent insights are derived (Linn & Muilenburg, 1996). It is constantly modified and refined as a result of successive experiences and reflections. Several technology-based science simulations (see, for example, Driver & Scanlon, 1988; Lewis et al., 1993; Rieber, 1992) as well as mathematics environments (see, for example, Edwards, 1995; Schwartz & Yerushalmy, 1987) nurture the *learner's* intentional model building and reconstruction. Learners design experiments, predict results, test and revise predictions, and revise both beliefs and strategies based upon their evolving understanding. The dynamic nature of understanding, then, requires that it be acted and reflected upon and constantly refined (Karmiloff-Smith & Inhelder, 1975; Schön, 1983).

Individuals must assume greater responsibility for their learning

While numerous positive results have been reported, negative consequences – both cognitive and affective – may also result from dependence on externally-driven teaching and learning. Attribution theorists have speculated that external control tends to minimize the personal investment and responsibility individuals feel for their learning. This was a driving force behind the early movement for increased learner control of computer-based instruction (Hannafin & Rieber, 1989a). Since they have little control over what is taught or how it is taught, many learners fail to assume responsibility for their learning, pointing to problems with teachers or materials. Presumably, given the opportunity to make their own choices, individuals evolve greater responsibility for their learning.

Evidence also exists to suggest that learners become increasingly compliant in their thinking (McCaslin & Good, 1992). They tend to view the learning task as matching the expectations of external agents rather than pursuing personal understanding. As perceptions are reinforced through external evidence of success (e.g., test scores), the cycle strengthens and perpetuates. Learners attempt to model external views of importance rather than evaluate their own needs and pursue understanding accordingly.

Technology-enhanced student-centered learning environments require that individuals are active in the learning process. They emphasize not only assimilation but the development of meta-knowledge for both solving existing problems and generating new ones. Through experience, learners become increasingly facile with available tools and resources, and skilled in assessing how and when to employ them. Learning environments often utilize activities that aid learners in constructing and generating artifacts of their understanding. [See, for instance, open-ended programming (Harel & Papert, 1991), evaluative, interactive essays (Thurber, Macy, & Pope, 1991), multimedia projects (Pea, 1991), and personally relevant health goals (Lebow & Johnson, 1993)].

Increased responsibility may also encourage awareness of the knowledge construction process. Cunningham (1987) refers to this as reflexivity and suggests activities that encourage learners to evolve a richer understanding of their beliefs. Influencing learners to become active in inducing mental activities enables them to reproduce thought processes intentionally without explicit external prompting (Scardamalia et al., 1989). Technology-enhanced student-centered environments require greater individual direction, but they may also promote self-sufficiency.

Yet, there remain many instances where externally-facilitated approaches are necessary and appropriate. As noted previously, learners often lack core knowledge or skills, such as word recognition or simple arithmetic, needed to engage in complex reasoning. When not effectively scaffolded, learners' executive functions may be best facilitated directly by external agents: the teacher designs and presents the instruction; the workbook provides exercises and questions; the computer presents tutorial information and confirms leaning mastery. Many learners cannot effectively engage higher-order tasks until they acquire sufficient background knowledge or skill. In such instances, conventional directed learning approaches support the automization of important foundation knowledge and skills (cf. Perkins, 1993).

Learners make, or can be guided to make, effective choices

Constructivists stress that learners determine what, when, and how learning will occur. Such methods, however, tacitly presume that students possess the metacognitive skills needed to make effective judgments, or can be induced to make appropriate choices using advice or hints (Hannafin, Hill, & Land, in press). Yet, ineffective strategy monitoring and usage have been observed in numerous technology-based learner control studies (Steinberg, 1977; 1989). These are serious concerns since learning environments rely heavily on the quality of individual learner decisions for their success.

Technology-enhanced student-centered systems rely on the learner to generate and implement individual learning plans. Judgments may be based on the individual's assessments of learning needs or those which, though made by the learner, are guided by the system. Guidance is provided in the form of tools, resources, and, if needed, direct instruction. Individuals can be guided during learning *if* designs are situated in authentically complex contexts and proper guidance is provided (Pea, 1993; White & Horwitz, 1987). For instance, athletes such as gymnasts or dancers are often "spotted" when they learn new routines. Performance is initially facilitated to enable actions which they are unable to produce independently. Successful learners, like successful athletes, gradually use facilitated action to perceive critical elements of the process and build upon them until they are able to perform independently; guidance is reduced and eventually eliminated as familiarity and facility increase. Student-centered environments use technological resources to facilitate the perception of critical processes and to provide experiences that approximate the requirements of an activity (Choi & Hannafin, 1995). With proper guidance, learners can understand in ways otherwise impossible.

Others have designed broad frameworks within which students specify a problem to be solved or goal to be pursued (see for example, the *Jasper Woodbury* series, Cognition and Technology Group at Vanderbilt, 1992). Within anchored contexts, students are provided the resources necessary to generate and solve problems. Thus, as students define a need to know, they access information from menus, books, peers, instructors, or other resources to locate information deemed helpful. Generic thought and probe questions are often available to consider, but they augment the thinking of individuals, and do not provide explicit solutions.

Guidance can also be solicited as a natural consequence of manipulation and experimentation. These features support learners in working toward a goal, exploring and testing relationships, and evaluating results. For example, failure to attain one's goal often provides the basis for seeking additional information. As learners recognize further needs to know, they begin to acquire the insight essential for understanding to occur (Bransford et al., 1989).

Guidance is often essential, however, for learners to reflect upon thoughts, intentions, and system feedback as they work within the environment. Evidence suggests that learners may not easily recognize limitations in their theories or beliefs without concrete opportunities to evaluate them (Land & Hannafin, in press). Determining the implicit cognitive triggering mechanisms – the events likely to cause learners to seek or invoke the appropriate support – is essential to effective design.

Learners perform best when varied/multiple representations are supported

Gagné & Merrill (1990) noted that conceptually-complex learning goals are often problematic in traditional instruction. Complex goals are qualitatively different from rule-based learning and objectives-based instructional goals. Spiro et al. (1991), for example, noted the need for multiple contexts, purposes, and resources in order to construct knowledge for individual purposes. Complex concepts, due to their ill-structured and highly conditional nature, require multiple representations.

Technology-enhanced student-centered learning environments strive to support the individual's efforts to both organize and represent knowledge. Learners are assisted in connecting relevant knowledge via varied representations and opportunities to interact with, and construct meaningful relationships among, the phenomenon under study. *Bubble Dialogue* (Language Development and Hypermedia Research Group, 1992), for example, allows learners to manipulate thoughts and ideas through unstructured internal and external dialog, encouraging sharing of viewpoints and perspectives across users. Similarly, Harel & Papert (1991) examined how fifth graders adapt multiple perspectives and purposes (e.g., programmer, teacher, learner; concrete, abstract; competing perspectives and opinions) to construct personal understandings of fraction use. *Citizen Kane* (Spiro et al., 1991) utilizes random access (hypertext) principles to support the learner in criss-crossing contexts and case irregularities to promote understanding. Varied methods and activities help to promote deep, flexible understanding.

Knowledge is most meaningful when rooted in relevant, scaffolded contexts

Instructional methods typically proceed from concrete to abstract as quickly as developmentally possible. Abstract knowledge is considered desirable, since it is presumed to be context-independent and transferable. Recently, some researchers and theorists have questioned this emphasis. Compelling evidence contraindicating such practices have been reported in studies of science and mathematics misunderstandings (diSessa, 1982; Lee, Eichinger, Anderson, Berkheimer, & Blakeslee, 1993; McDermott, 1984; Perkins & Simmons, 1988). Although able to apply abstract rules in textbook-like problems, fundamental learner misconceptions often surface for non-standard problems. Many researchers believe that to-be-learned knowledge and its associated cognitive processes cannot be separated from their concrete referents (Perkins & Salomon, 1989). Concrete contexts allow learners to evolve understand through use.

Technology-enhanced student-centered learning environments are designed to facilitate the unique construction of understanding. However, understanding is not viewed as solely an internal process occurring "... as a property of the minds of individuals" (Pea, 1993, p. 47). Understanding is a goal-directed activity that, although ultimately internalized, takes place within an "... influential and responsive social context" (Belmont, 1989, p. 142). As such, the role of the environment cannot be separated from understanding; it is profoundly influenced by contexts which frame learning processes.

In technology-enhanced student-centered learning environments, the processes associated with understanding and the contexts in which it occurs are inextricably tied. Rather than isolating information, it is embedded in contexts wherein knowledge and skills reside naturally. *Science Vision* (Tobin & Dawson, 1992) immerses learners in problem contexts that promote learning activities that are consonant with practices of experts. Students learn about physics by designing a virtual roller coaster; they study ecology and chemistry by resolving problems related to polluted water. The environment is considered authentic because it induces participation in realistic activities and science processes of the scientific community. Information anchored in relevant contexts enables learners to explore as a scientist to reveal why, when, and how knowledge is used (Cognition and Technology Group at Vanderbilt, 1992).

Traditionally, learning has been viewed as a process internal to, and possessed by, the learner. Recently attention has emphasized the social nature of cognition (Bandura, 1982; Brown et al., 1989; Lave & Wenger, 1991; Perkins, 1993). Cognition, it is proposed, is not possessed solely by learners; instead, it is constructed and acted upon as a shared enterprise (Belmont, 1989). From a social cognition perspective, thinking is viewed as the basis of activity that requires an interpersonal context to develop. As such, learning can be analyzed by examining interactions of learners, individually and collectively, within that context.

The shared, social construction of understanding underlies the design of many student-centered environments. Many approaches have utilized teacher-student or student-student interactions to model or scaffold reflection and performance (see for example, Palincsar & Brown, 1984; Scardamalia & Bereiter, 1985). In such environments, teachers coach and "... model expert strategies in a problem context shared directly and immediately with students" (Collins, Brown, & Newman, 1989, p. 463). Scaffolding is provided in the skills and processes necessary to carry out a thought, task, or operation. Over time, the teacher's involvement is gradually faded and the responsibility for learning is increasingly assumed by the learners. Such interactions effect the *sharing* of sense-making processes and progressive refinement of ideas. In subsequent interactions, students assume the dual roles of producers and critics (Collins et al., 1989).

Scaffolding, however, is not limited solely to student-student and teacher-student interactions. Rather, technology-enhanced environments often provide the conceptual scaffolding and means (resources, tools) to promote personal and individual reflection. In this sense, technological tools "... provide models, opportunity for higher level thinking, and metacognitive guidance ... in a learner's zone of proximal development" (Salomon, Globerson, & Guterman, 1989, p. 620). The features of a learning environment (tools, resources, people, designs) profoundly shape, direct, and constrain how learners think. They enable occasions – often transitional in nature – during which rich learning opportunities are created. Learners may think or understand in ways that would normally be impossible without technology-supported scaffolding (Salomon et al., 1991).

Technology-enhanced student-centered environments provide the opportunity to engage higher-order processes, test on-going hypotheses, and construct and revise physical models of concepts under study. In combination with guidance and facilitation of the learning process, technology can serve as a "more capable peer" (Salomon et al., 1989, p. 621). *CSILE* (Scardamalia et al., 1989) provides a series of organizing prompts that help students to internalize new thinking processes and reduce the accompanying processing load associated with the cognitive task (Salomon et al., 1991). The social context for student-centered learning may include human and/or technological partnerships.

Understanding is most relevant when rooted in personal experience

In many teaching and learning settings, information is extracted from its native contexts to simplify the learning task and avoid potential confounding from extraneous, and presumably unnecessary, information. Information is structured and presented so that individuals can learn *about* important information. Yet, evidence suggests that children often fail to connect abstract, formal notions since the concepts are not physically accessible to them. Learning is more concrete and meaningful as more personal connections are made among ideas, contexts, perspectives, and the models that represent them (Wilensky, 1991). It appears that simply supplying conceptual information to learners and allowing them to practice does not necessarily deepen understanding of concepts.

Contemporary researchers and theorists suggest that understanding is facilitated when derived from rich, hands-on experience (APA, 1992; Linn & Muilenburg, 1996; National Science Teachers' Association, 1993; Perkins, 1991). Experience enables the learner to reshape and revise ongoing theories-in-action based upon personal sense-making efforts. In the practice of science, for example, scientists espouse notions such as "getting to know" an idea, exploring a body of knowledge, and becoming sensitive to distinctions in the learning process (Papert, 1993b). Scientists emphasize the importance of encountering objects or concepts under study – experiencing them – rather than being told *about* them.

Technology enables learners to become immersed in concrete experiences – or phenomenaria (Perkins, 1991) – rather than presenting information about them. Learners derive not only formal understandings from their experience, but deeper insights into the subtleties of the concepts under study. Opportunities are provided for students to vary conditions or parameters, increase or decrease complexity, and manipulate normally abstract concepts in tangible ways. Activities maximize the learning experience by presenting phenomena in ways that make them amenable to both scrutiny and manipulation, such as the manipulation of Newtonian motion concepts (e.g., Rieber, 1992; White & Horwitz, 1987). Learning environments provide contexts that are rich in experience, knowledge, and opportunity potential.

Reality is personally constructed via interpretation and negotiation

Perkins & Simmons (1988) reported that, following traditional mathematical instruction, learners retained fundamentally naive beliefs despite the ability to readily apply formal knowledge to solve textbook problems. When problems failed to match prototypical textbook structures, naive and incomplete perceptions surfaced. Formal knowledge was over-generalized and little attention focused on whether solutions were reasonable or possible. Learners acquired formal knowledge but failed to understand.

Content-driven instructional approaches may hamper deep understanding in favor of breadth of coverage, or limit perseverance for the sake of efficiency. Traditional science labs, even with their focus on hands-on-experience, often emphasize finding a definitive answer or illustrating a particular scientific truth. Although such methods may help students concretize some concepts, they essentially *tell* students why specific scientific phenomenon occur and reinforce canonical truth. Piaget (1952) noted that understanding is rooted in initial intuitions or models and evolves as learners correct, reinforce, or differentiate initial notions. After preconceptions are identified, conveyed, and adhered to in the face of conflicting experiences, learners begin to question the limitations of their models and formulate new, integrated structures (see also Ackermann, 1991).

Student-centered learning environments attempt to support personal theory-building and theory-enhancing. Although personal theories or models may be incomplete initially, learners become immersed in experiences that allow them to identify, make and test predictions, and modify their intuitions. Errors, discrepancies, and misconceptions provide the basis for refining understanding. Learners formulate initial and often "flawed" beliefs, but subsequently evolve understandings through manipulation and experimentation. These beliefs help to establish assumptions that can be subsequently tested. Imposing canonical beliefs, without allowing opportunities for learners to create and test their own, may short-circuit the opportunity to reconcile intuitions with instruction.

Understanding requires time

Understanding is cultivated via methods that emphasize investigation and exploration. By spending time immersed in a problem, learners encounter intricacies and subtleties that are of interest, enabling them to explore a domain in rich, meaningful ways (Papert, 1993a). They progress from simply knowing to understanding. They can better discover what they need to know *if* their efforts are supported socially, materially, and technologically. Thus, "playing with problems" – exploring, predicting, manipulating, and testing – leads to qualitatively different learning goals. These goals build upon experience and intuition, which requires immersion.

Student-centered learning environments assume that understanding is refined over time as a result of rich, concrete technology-facilitated interactions. Microworlds embody this assumption as they promote manipulation, model building, and revision of beliefs. Exploration leads to ideas about how or why a particular rule, equation, or concept exists. Pea (1993) noted that individuals must be introduced to, and participate in, activities that suggest or reveal underlying meaning to abstractions (such as an equation or notation system). Without extended exploration, understanding is often incomplete and rigid. Conceptual understanding becomes impoverished, inherently limiting learners in its utility. Understanding, and the insights derived through efforts to understand, requires sustained engagement in learner-centered activities.

Conclusions

Technology-enhanced student-centered learning environments are not simply dichotomous alternatives to direct instruction; they represent alternative approaches for fundamentally different learning goals. Any learning environment is ultimately shaped by its foundations and assumptions about learning, pedagogy, and the learner: As the assumptions change, the interplay among the foundations changes. The issue is not the inherent superiority of one approach over another, but recognition of the foundations, assumptions and methods appropriate to specific learning goals and cultures.

Student-centered learning environments, with or without technology, will not be the system of choice for all types of learning. In some instances, they may be impossible to justify. Some initial tool skills are likely best achieved via “basics first” approaches where knowledge and skills are separated from their contexts. Specific performance demands, time constraints, contextual demands, and the need to be productive quickly may militate against approaches that emphasize sustained study. Pragmatics often limit significantly the ways in which learning goals can be addressed.

It is important to recognize, however, that viable alternatives to direct instruction methods exist, alternatives that reflect different assumptions and draw upon different research and theory bases than do traditional approaches. The shifts are fundamental, not cosmetic or semantic in nature. The issue is not simply one of emphasizing similarities across approaches, but comprehending the differences in assumptions and foundations that underlie them. Simply renaming traditional processes, without altering basic beliefs about the processes themselves and the supporting methods, will not significantly alter the nature or quality of a learning environment. If we aim to address sophisticated learning goals involving in-depth study, problem solving, and reasoning, alternative assumptions, foundations, and methods must be developed.

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