COMMENTARY

Exploiting the Use of Technology to Teach: The Value of Distributed Cognition

Neil H. Schwartz
California State University, Chico

Teaching is a dynamic activity—a dynamic transaction between mind, materials, outcomes, and goals. Teachers teach; learners learn—all within the context of a complex cognitive and socio-cultural environment that is evolving faster than at any other time in the history of education. The principle factor responsible for this evolution is the development of technology—technological achievements at the end of the 20th Century that have revolutionized the way people communicate, exchange ideas, inform one another, and learn (U.S. Department of Education, 2005). This special issue is devoted to an examination of that achievement—not the achievement per se, but the way teachers learn to exploit technological achievements to teach—how the teaching-learning process is leveraged through the use of technology, and how teachers transform, and are transformed by, their experiences with technology.

And yet, there is a major contemporary problem with technology use in education. Technology does not see widespread implementation in the classroom. According to Rod Paige (2005), the former U.S. Secretary of Education, “Education is the only business still debating the usefulness of technology. Schools remain unchanged for the most part, despite numerous reforms and increased investments in computers and networks.” (p. 22). Even the U.S. Department of Education’s National Education Technology Report (2005) stated that, while virtually every public school has access to the Internet; in most schools “…it is business as usual. Computers are enclosed in computer rooms rather than being a central part of the learning experience.” (p. 22). The report contends that it “is not necessarily lack of funds, but the lack of adequate training and lack of understanding of how computers can be used to enrich the learning experience.” (p. 22). In the present journal, the latter issue has been addressed directly—the way computers and other technological devices need to be understood by teachers, and the way the devices can be successfully used to enhance the processes and outcomes of learning. The papers in this edition address this issue in the context of distributed cognition.

In the present paper, I will discuss distributed cognition as a heuristic with which to think about the way learners learn and teachers teach. First, I will inventory the basic tenets of the concept; next, I will consider learning from a distributed cognition point of view; finally, I will discuss distributed cognition relative to the findings of the investigations presented herein.
THE CONCEPT OF DISTRIBUTED COGNITION

The notion of distributed cognition is important to understand because it extends the concept of cognition as existing inside a learner's head, to cognition distributed within (Minsky, 1986) and between the internal cognitive architecture of learners and the objects they use to solve problems (Hutchins, 1995a, 1995b; Salomon, 1993). Thus, processes of learning taking place in the head are apportioned across members of a learning group, involve coordination between the members and objects (produced or imported) within the group, and are distributed through time to events taking place elsewhere (Hollan, Hutchins, & Kirsch, 2000). This means that cognition is propagated from mind to mind; mind to tool, and tool to mind in such a way that it: (a) is shared between the constituents of the group, (b) creates representations within and between the heads and manifest artifacts of the group, and (c) combines itself into a dynamic coordinated system (Hutchins & Clausen, 1998). Hutchins (1995) describes the cognition shared between Navy sailors navigating a large ship into port as an illustration of these components. Sailors on each side of a ship have to use telescopes to record the angular position of landmarks relative to the ship's gyrocompass at precise points in time. These readings have to be sent via the ship's telephone to the navigator. The navigator, in turn, must record the readings on a specific kind of chart to determine the ship's location and bearings so that the direction and speed of the ship can be transferred to, and adjusted by, the ship's captain. In short, the process requires the coordinated cognitive effort of multiple sailors using multiple instruments working together to allow the ship to be sailed into port without running aground. The process is not only complex, but no single individual could manage it cognitively alone. Hence, the task is accomplished via multiple minds, using multiple tools, executed under specific environments with specific intentions, all coordinated and distributed into a system.

The system of minds working together in the presence of tools is not an artificial concept. Many believe that distributed cognition is so fundamental to the way humans and environments interact, that humans may actually be neurologically designed to distribute their cognition across social and material dimensions of the environment (Vygotsky & Luria, 1994). Giere (2002) invokes findings from the PDP (parallel distributed processing) Research Group during the 1980's (McClelland & Rumelhart, 1986), Dynamic Systems Theory (Thelen & Smith, 1994), and conceptions from evolutionary psychology (Clark, 1997; Suchman, 1987; Varela, Thompson & Rosch, 1993) to support this contention. He points out that the human brain evolved for handling the actions necessary for successfully hunting, mating and rearing young—and not contemplation, per se. Thus, a single central cognitive processor for handling all human activity is not particularly convincing. Instead, there is evidence that the brain derives, stores, and recognizes patterns for use in reasoning with the objects, tools, situations, and devices necessary to solve problems. In effect, "Humans recognize patterns through the activation of prototypes embodied as changes in the activity of groups of neurons induced by sensory experience" (Giere, 2002, p. 3). Thus, individuals need external devices to think with (e.g. calculators, for-
mulae and spectrometers in chemistry; microscopes in biology; oscilloscopes in physics; reaction times and facial reactions in psychology) and it is only in the presence of these tools, grounded within the conditions for which they are employed, can cognition be successfully deployed. That means cognition is spread out—distributed—among the internal representations (as patterns) for which the devices give rise, and the devices as entities in the environment. It also means that humans as learners are predisposed to function with external devices and other humans—distributed in a system of cognition, and the artifacts and tools of cognition—in precisely this fashion.

CONSIDERING DISTRIBUTED COGNITION FOR LEARNING

When cognition is considered as a distributed system, it opens up the processes of learning to inspection. This is important for teaching with technology because inspection permits teachers to examine the variables involved in the process of learning. It focuses teachers' attention on their, as well as their students', cognitive events during the time their students are attempting to learn. It permits teachers to be mindful of the recursive and reciprocal influence their learners have on the things they do to teach, as well as the activities their students engage in to learn. It also makes salient the artifacts students leave behind from their attempts at understanding. Finally, and most importantly, distributed cognition, as a perspective with which to think, has the potential to increase the likelihood that teachers will make careful selections of the tools they employ for teaching.

And yet, conceptions underlying the notion of distributed cognition are not new. After all, Cole and Engestrom (1993) pointed out that the work of Wundt (1921) and Munsterberg (1914) were intimately concerned with the influence of mind and environment together. As Cole and Engestrom put it, "In modern terms, Wundt was arguing that while elementary psychological functions may be considered 'in the head,' higher psychological functions require additional cognitive resources that are to be found in the sociocultural milieu" (p. 3). Similarly, Munsterberg (1914) contended that "Cognition occurs not only 'in the head'... but in the objective elements of communication among individuals" (Cole & Engestrom, 1993, p. 3). Even Karasavvidis (2002) pointed out that the resurgent interest in mind in the 1950's followed dissatisfaction of behavioral concepts and ideas—not only dissatisfaction with a focus on behavior alone, but ultimately with the mind-body dualism of Plato & Descartes from which the behavioral focus originally emanated. Karasavvidis' point is an essential one because it obviates the social evolution of human thought—a collective consciousness that is slow to change. It is also important because it underscores the social infrastructure underlying the thinking of a group—in this case, researchers dialoguing and writing over time within a common epistemology.

The point to be made about distributed cognition both historically and today is that learning is cognitive and social. As such, teachers have a considerable impact on their learners, not only in terms of the things they say and do, but also on the tools they select for instruction. That means it is essential to understand what beliefs, attitudes, and experiences teachers bring with them when con-
sidering which technology tools to use (Mumtaz, 2000; Tearle, 2003; Zhao & Cziko, 2001); it also means that teachers must become aware of learning as an effective socio-cognitive function (Suthers, 2005).

Thinking of technology as tools. At a fundamental level, technology offers tools (e.g., word processing programs to write, graphics programs to visualize)—tools that permit learners to search for and find information, organize and present knowledge, explore simulated environments, participate in authentic learning environments, communicate and collaborate with other students, and practice and receive feedback on the development of skills; powerful devices with which to teach and learn (Jonassen & Carr, 1999), but tools nonetheless.

The problem is that teachers, who know neither how to use these tools, nor what to build with the tools they use, are at a significant disadvantage in the classroom. The former is an issue of competence; the latter is an issue of knowing what to construct. Doering, Huffman, and Hughes (2003), for example, revealed that pre-service teachers are seriously limited in their ability to consider how to go about implementing technology into the teaching activities they conduct. Keren-Kolb and Fishman (2006) implicated, as limiting, the beliefs teachers hold about technology prior to their teaching apprenticeships. Both the findings underscore the governing effect of teachers’ internal cognitive conceptions—conceptions that function to occlude their understanding of learning tools as principally cognitive.

I suggest that teachers find it difficult to use technology to teach because they fail to think of technology as cognitive tools. This is a major shortcoming because learners perpetually interact with tools when attempting to learn, and teachers make heavy use of tools when teaching. The point is that the teaching and learning process is negotiated and transacted between and within these tools and the agents who use them, and while the transactions are certainly social and cultural, they are also always cognitive. Schwartz and Ligorio (2004) put it this way, “For successful learning to occur, teachers and learners must negotiate the transaction of knowledge at the juncture of what students need to know and what teachers understand about knowing” (p. 301). Understanding that learners require tools to think and learn is the crux of effectively teaching with tools.

Thus, careful selection of teaching materials as tools is a fundamental limitation among teachers in their implementation of technology. In part, this exists because teachers fail to think of technology as thinking tools capable of enhancing learning (Yuen & Ma, 2002). Teachers also fail to approach teaching using a framework with which to think that embodies both mind and tools within a dynamic system of active learning (Angeli & Valanides, 2005; Mishra & Koehler, 2006; Totter, Stuerz, & Grote, 2006). This is particularly troublesome because some researchers have shown significant success of teachers’ use of instructional tools when they are offered a model of instructional systems design that permits them to think more constructively (c.f., Angeli, 2005). One question is whether distributed cognition provides heuristics for thinking about the way teachers think about the role and efficacy of technology in learning and instruction.
Beliefs about learning and technology. Karasavvidis (2002) made the following observation:

"Much of current educational practice is founded on the assumption that cognition resides in the individual head. The conception of the individual as the sole bearer of all cognition is widespread and is manifested in the conceptions of teaching and learning methods as well as in the classroom and examination practices. The underlying assumption is that the learner is a passive recipient of information and that teaching is the process through which the teacher instills information in the heads of the learners, who will in turn commit this information to memory where it will hopefully be maintained for future retrieval. Even ostensibly more interactive forms of teaching such as Socratic dialogue and questioning are also indicative of the penchant to view cognition as a property of the person as, even in the case of questioning, the bulk of the information and the major cognitive structure is still provided by the teacher with the students filling in the open slots." (p. 22)

Thus, one of the most pervasive problems in getting teachers to use technology to teach is borne from their conceptions of learning. Most teachers hold epistemological beliefs about knowledge and learning that are dualistic in nature—that is, they are held as properties of the individual mind (Hofer & Pintrich, 2002). This is a major impediment to the employment of technology in teaching because knowledge has been traditionally viewed by most teachers as an entity that can be packaged and sent, independent of a teacher’s and learner’s interaction with it. These conceptions have been demonstrated as amenable to change in both teachers (Brownlee, Purdie, & Boulton-Lewis, 2001; Howard, McGee, Schwartz, & Purcell, 2000), and learners (Azevedo, 2005a, 2005b, in press; Schwartz, Stroud, Hong, Lee, Scott, & McGee, 2006; Tsai, 2005) but it is not clear whether the changes are long lasting over time. It is also not clear whether the use of technology can stimulate these changes within and between teachers operating in the context of the socio-cognitive milieu of the school culture.

Thinking as a socio-cognitive function. Schools are cultural entities in so far as they consist of constituent entities that comprise them (teachers, students, teachers’ aides, parents, parent groups, principals, school psychologists and counselors, etc.). Each of these entities functions under clear roles and structural relationships between these roles that influence and regulate behavior, expectations, goal setting, and plans. There are also clear norms that develop between and within constituent groups. Thus, the teaching-learning environment, as a distributed cognitive system, is steeped in the socio-cultural factors of the school, not unlike the socio-cultural factors indigenous to the distributed cognitive system of sailors in the navy. In Hutchins’ (1995) illustration, for example, the social structure of the ship in terms of military ranks and their responsibilities, in addition to the norms, values, and goals of navy culture, all play a role in the distributed cognitive system operating when bringing a ship into port. But,
these factors also operate among teachers and learners within the socio-cultural fabric of the school, and it is essential to consider them when examining the synthesis of technology into the teaching-learning process.

Thinking of learning with technology as a socio-cognitive function has been characterized by Koschmann (2002) in the context of discussions of computer supported collaborative learning (CSCL). Koschmann characterizes CSCL as practices of meaning making in the context of joint activity and the ways in which these practices are mediated through design artifacts. And, while Koschmann is not writing under the auspices of distributed cognition, the concept to which he speaks is clearly distributed. In other words, it suggests that people must be engaged in activity in the presence of material—artifacts of the minds of each participant as well as the minds of the designers who create the computer-based collaboration tools. Thus, learning in computer supported collaborative learning groups takes place within a system—a system of minds, tools, and artifacts regarded as the hallmark of the distributed cognition perspective.

Cultural dimensions, then, are manifested within the minds of learners while concomitantly existing as artifacts surrounding those minds. Thus, words, gestures, objects, appliances, and tools, etc.—even the sequence and timing of the use or exhibition of them—carry with them considerations of meaning that are propagated one to the other by convention, history, and shared expectation within a community over time. These conventions do not exist in mind, or in the manifest artifacts of the environment, but in the collective union of both. In short, cultural elements of learning are situated within and between minds in the context of their historical and current productions. The problem is that teachers and other constituencies of the school do not yet think of technology as an integral part of the evolution of knowledge among the critical members of the school culture.

While research on CSCL can be regarded as a particular application of distributed cognition, there are epistemologies underlying CSCL that can inform the practices of teachers’ use of technology. They also can be used to inform the investigations reported in this issue. Suthers (2005), for example, elucidates four overlapping epistemologies that are borne from CSCL and relevant to our discussion here. One concerns the communication of knowledge; the second with the construction of knowledge collaboratively; the third with the commonality of ground that is necessary for learning partners to bring to their meaning making transactions; and the fourth with knowledge building that is self- and collectively-reflective. The first arises from the writing of Wenger (1987) who characterized the communication of knowledge as: “The ability to cause and/or support the acquisition of one’s knowledge by someone else, via a restricted set of communication operations” (p. 7). The second refers to an individual’s efforts to build meaning of the world via a problem solving exploratory method of activity that is volitional, data driven, and intentional (Piaget, 1976; von Glaserfeld, 1995). The third is explained in terms of the inter-subjectivity between individuals in a learning group; that is, the notion that learning takes place between people on the basis of the interpretations they share among each other—crafted and re-crafted until a sense of homeostasis of thought is achieved.
between them (Clarke & Brennan, 1991; Koschmann, Zemel, Conlee-Stevens, Young, Robbs, & Barhart, 2005). The fourth is based in the writings of Scardamalia and Bereiter (1991); individuals build knowledge among each other as a community and expand the boundaries of that knowledge by reflecting on their collective limits of understanding. Both the latter two epistemologies are the more extensive of the four, and in my opinion the most relevant for teachers’ use of technology under the auspices of distributed cognition.

ISSUES REVEALED BY THE INVESTIGATIONS IN THIS ISSUE

There are several issues illustrated by the investigations in this issue that bring out the heuristic value of distributed cognition for technology use in schools.

Issues related to the role and function of mind in learning. In the first epistemology above, for example, Suthers (2005) makes the point that communication of knowledge is critical in understanding teachers’ successful use of technology. Yet, Narciss and Koenndle (this issue) make the point that the expertise of teachers and learners in mindfully accessing and using technical tools to construct and communicate knowledge was actually rather low. This finding introduces an interesting and ironic paradox. The irony is situated in the fact that mindful access and use of technical tools to facilitate the construction of knowledge among learners is based on socio-constructivist notions of meaning making; that is, that expertise can only be derived from a deep understanding of the way learners construct meaning together. However, the issue is that teachers who guide these transactions must also have knowledge of human cognitive architecture in order to understand the transactions they guide. Thus, without an understanding of the way learners process information, it is difficult to scaffold the meaning-making process, or to regulate the way in which to sculpt the transactions between teacher and learner groups. This goes well beyond knowledge of the technology teachers use to teach; it implicates an understanding of mind—inside mind—in addition to the way the mind interacts with other minds in the context of this technology.

Interestingly, the issue also obviates the tension between cognitive and socio-constructivist views of learning in the context of the way learners learn and teachers teach (cf. Derry, 1996; Dillenbourg, 2006; Kirschner, Sweller & Clark, 2006). According to Giere (2002), constructivism is currently the dominant meta-theory of the way we conduct science; as such, cognitive operations are marginalized because so much of what seems important to understand takes place between individuals in the context of the socio-cultural milieu, rather than in the head of the learner. However, Giere (2002) makes a convincing case that distributed cognition bridges the two theoretical/philosophical domains and renders the tension between meta-theories moot. He writes,

From the perspective of distributed cognition, what many regard as purely social determinants of scientific belief can be seen as part of a cognitive system, and thus within the purview of a cognitive understanding of science. There is no longer a sharp divide. The cognitive and the social overlap. (p. 13)
Thus, the issue highlighted by Narciss and Koerndle's (this issue) finding does not necessarily apply strictly to teachers' understanding about the way technology can and should be used, but to teachers' conceptions of the cognitive processes learners deploy to think with the tools of the technology. This is in addition to the social and cognitive transactions between learners and teachers in the context of the materials and tools they use, afforded by the technology.

The point here is that this dual position is not simply a middle ground between the two epistemologies per se; it is a sensible and reconciled position under the auspices of cognition conceived as distributed within a social and embodied system.

In another issue, Suthers (2005) points out that the collaborative construction of knowledge is incumbent upon the efforts learners use to intentionally and volitionally build meaning. Narciss and Koerndle's (this issue) findings inform this issue as well. Their data validate the point, revealing that, while it is difficult to do, teachers must not only master subject-matter knowledge, but knowledge on how to scaffold social interactions in small groups. That is, simply putting students in cooperative learning environments does not necessarily mean that the students are going to cooperate or collaborate cognitively.

This raises an interesting point. The negotiation of meaning and knowledge building is the sine qua non of social-constructivist thinking about learning. Indeed meaning, and the knowledge developed from meaning, is the most fundamental index of learning outcomes. However, collaborative and cooperative activities do not always yield effective meaning making between learners, or between learners and teachers. In fact, Narciss and Koerndle's (this issue) data suggest that they do not. Thus, since learners are not always cognitively engaged, it is incumbent upon teachers to examine the internal cognitive events of learners (e.g., their beliefs, expectations, anticipations, and goals) which preclude their engagement. A related and nagging issue is whether teachers have the knowledge and expertise to derive rich and utilitarian hypotheses about these cognitive events between and within their students.

Fortunately, distributed cognition affords an opportunity to examine shared meaning and transaction of meaning between students and teachers through the artifacts each produce. The key, however, (and the point above) is to know something about how to go about the interpretation of these artifacts to understand the knowledge behind them. This of course is not always easy; however, three elements seem to inform the issue. One is related to the opportunity to reflect on the learning process and the tools afforded to reveal them. A second is related to the time these reflections are made. The third is whether reflections are focused on the outcomes or processes of learning operating to produce those outcomes.

**Issues related to the processes and products of learning.** In Narciss and Koerndle's (this issue) work, for example, while teachers were given time to reflect on their own and their students understanding via the technological tools afforded them, the reflections were for the most part retrospective. This is not uncommon methodologically among investigations of this type. However, one of the issues is that, while it is no doubt essential to index knowledge acquisition as
the relevant outcome of learning, information may be lost in focusing on learning outcomes and teachers' and students' reflections on them, a posteriori.

Here distributed cognition is helpful as well. Conceptions borne from distributed cognition underscore the necessity of examining the processes underlying learning, rather than the products borne from the processes, per se. Thus, it is essential to examine learning productions, during the time they are produced, as artifacts of learning processes, and the way the transactions can and should change to exploit further transactions. This is a challenging task for designers of computer-based classroom tools. However, it is important to consider designing technology tools in such a way that they can be modified, or permit adaptations of use, while the teachers and students are using them. These types of tools allow for learning and cognitive processes to be seen and for teachers to change the way they transact knowledge during process deployment.

The other point is related to the time at which technology tools provide for modification of learning scaffolds. That is, designers must be careful about preparing cognitive scaffolds a priori. Scaffolds are precisely the kinds of frameworks that need to be used during the cognitive transactions that take place between teachers and learners, and learners and teachers, during learning. However, if cognitive conceptions are shared, transferred, changed, and evolved in a system of cognitive distribution, then scaffolds can only be authentic and effective if they are customized at the time of transaction—customized to the level of understanding of both teacher and learner sharing knowledge of subject matter and knowledge of the processing of that subject matter at critical points in time.

Näyyki and Järvelä (this issue), dealt with this issue directly. Their investigation examined learning processes during the construction of collaborative knowledge when technology afforded pictorial representations to be used for visualizing knowledge elements among learners. Here the focus was on the process of knowledge construction, not the outcomes of the process per se, and the tools enabling the construction of knowledge to be distributed throughout the system. Narciss and Koerndle (this issue), and Ligorio et al. (this issue) focused on learning processes as well. Furthermore, Valanides and Angeli (this issue) underscored the importance of the issue, commenting "the design of educational software for young children should afford scaffolds for helping them to recognize and manage cognitive conflict. Scaffolds for recognizing and managing cognitive conflict can take the form of question and reflection prompts every time a discrepant event arises that is presented to the learners." (page 331) Thus, the point is that scaffolds need to be customized for each student's cognitive needs, and responsive enough temporally to be delivered at the time students need them.

**Issues borne from the concept of transitivity.** Suthers (2005) made the point that commonality of ground is necessary for learning partners to make meaning of their transactions. This is related to the idea that learning takes place between people on the basis of the interpretations they share—the concept of intersubjectivity between individuals in a learning group; this is "the process occurring between people, particularly between a competent adult and a less competent
child, where the social interaction between the two generates new understandings beyond the mere combination of each individual's point of view" (Ligorio et al., this issue, page 340). There are three issues inherent in the concept of intersubjectivity as Ligorio et al. use it here. One relates to the intents, perceptions, and goals learners and teachers bring to the technology tools they use; the second is the imparity of skill and subject matter knowledge among learners and their teachers in a technologically mediated learning group; the third is the capacity of distributed cognition to be able to deal heuristically with the imparity in terms of properties of cultural mediation.

With regard to the first, Ligorio et al. (this issue) make the point that "The complexity intersubjectivity takes on is not necessarily more elaborate because of the patterns borne from the interactions per se, but rather because of the mutuality of understanding propagating between members of the system" (page 341). As such, the mutuality of understanding is the raison d'être of learning within groups, and the principal reason for which technological devices as learning tools are designed, built, and placed within classrooms. However, in order to be successfully used, teachers and students must have a sense of their own as well as each other's roles, knowledge, and intents in being able to use them. This is an important issue to underscore because learners and their teachers approach technology use with significantly varied thinking skills and goals, and it is not always apparent how the tools should be used or what should be obtained from using them.

Valanides and Angeli (this issue) and Näykki and Järvelä (this issue) make the point as well. Valanides and Angeli write that what

needs to be considered in the design of educational software systems for children is the learners' perceptions of the task, and how often [these perceptions] need to be taken into consideration"; that "learners' perceptions of the task heavily operate in the learning task as they easily get distributed and are just as viable as other more concept-related cognitions (pages 331–332).

Näykki and Järvelä write that "The efficient extended cognitive system, as it is the case in group learning, requires the negotiation and coordination of group members' diverse views [and] presumes some amount of shared understanding" (page 360). Thus, the point, from an intersubjectivity point of view, centers on the mutuality and reciprocity of the goals, intentions, and roles among all the members of a learning group, and whether tools can scaffold, support, and reveal the operation of these elements while teachers and learners are engaged in the process of learning together.

The second issue that intersubjectivity brings to bear is the imparity existing between teachers and learners operating together within a system. It is useful to consider the issue in terms of distributed cognition.

Learners and teachers operating with technology tools approach the tools and the learning task with widely diverse levels of expertise. Thus, how are distributed cognitive systems to be developed when some of the minds comprising the
system are unskilled? In what ways do teachers operate with students within a distributed learning system when the teachers are skilled in the subject matter, but their students are not? In the case of ODRES, for example, (Valanides & Angeli, this issue), should the tool respond to changes in a students’ understanding of the concept, or the teachers’ appraisal of the changes the student reveals? ODRES is a tool designed to allow students to develop a conceptual understanding of a specific property of optics, built to incur the concept by way of reasoning. However, how does reasoning, as a function of mind, propagate between two minds—teacher and learner—or two minds and a tool when one of the minds possesses conceptual expertise and the other does not? Is reasoning shared between teacher and learner when cognition is distributed in a system; and if so, how? The answers to these questions are not entirely clear. But, the issue borne from the aggregate of them is important to consider for designing tools to learn under the purview of conceptions of distributed cognition.

Finally, in their discussion of transitivity, Ligorio et al. (this issue) cite Cole and Engestrom (1993) in the following quote, “Cultural mediation has a recursive, bidirectional effect; mediated activity simultaneously modifies both the environment and the subject” (p. 9). Thus, the third issue the concept of transitivity reveals is whether distributed cognition can be imported as a heuristic for the development of the individual and collective cognition of teachers and learners distributed in a system of learning tools. Specifically, if the constituent groups operating within a learning environment (e.g. teachers and learners), and the learning environment itself, both change, it is puzzling how distributed cognition as a concept can account for the evolution of the system. After all, the minds comprising a system of distributed cognition, as explained by Hutchins (1995), are skilled enough to use the tools coordinately, and relatively invariantly, in contribution to the system as a whole. This is in stark contrast to the emergent, transformational, and evolutionary properties of a “learning” system.

Unlike distributed cognitive systems comprised of experts, teaching-learning environments—even conceived as cognitively distributed—are “in development” with the purpose of the system not necessarily targeted toward a goal that is well delineated (other than to change). Distributed cognitive environments, as illustrated by Hutchins (1995) on the other hand, are relatively fixed in purpose, as in successfully flying a plane and bringing a large ship into port. Thus, the purpose of learning environments, (as distributed systems between learners, teachers, and tools), is to be transformed—to evolve from relative levels of naïveté to some level of expertise; in short to learn, and become better at the process of learning. This is cultural mediation defined in the context of schools such that the development of knowledge, skills, and values evolves via recursion, bi-directionality, and concomitant change into a more informed strategic and effective learning system. However, the issue is whether distributed cognition, as it is generally conceived, can handle this evolution.

**Issues related to the artifacts of learning.** The final issue the papers in this edition address is the extent to which technology provides the capacity to leave representations behind so that the artifacts can serve as scaffolds to enhance the learning process. This issue yields two related facets with which to deal. One
relates to the off-loading function of mind in the context of distributed learning transactions. The other relates to the affordances of meaning these off-loaded artifacts reveal—the capacity the affordances serve to help teachers better teach concepts, and the learners better learn the concepts teachers are attempting to teach. Narciss and Koerndle’s (this issue) tools, Valanides and Angelis’s (this issue) ODRES, Ligorio et al.’s (this issue) virtual space, and Näykki and Järvelä’s (this issue) maps are all grounded examples.

The role of the material environment serves to hold representations from mind so that limitations of the cognitive system can be relieved. Off-loading serves to reduce both intrinsic and extraneous cognitive load (c.f. van Merriënboer & Sweller, 2005), so that learners can summon strategies from mind and distribute them to placeholders in the environment—placeholders either produced by mind or objects as placeholders that are already contained there.

In the distributed cognition literature, the example is often given of the shopper who solved the problem of an erroneously high-priced package of cheese. Instead of using arithmetic to validate the error, the shopper searched and found a similar weighted block of cheese, observed the price-weight discrepancy, and solved the disparity in the prices. Thus, the computation was offloaded onto the environment, and the two packages of cheese were employed as cognitive tools to solve the problem (Lave, Murtaugh, & de la Rocha, 1984). Thus, distributed cognition provides a valuable heuristic to theoretical issues related to the artifacts of mind by recognizing that the tools used to think not only free the mind to think, but also reveal much about the thinker; they also lead to manipulations of the learning environment that can lead to deeper learning.

FINAL REMARKS

Giere (2002) gives an example of cultural mediation, and hence system change vis-à-vis distributed cognition, in the context of the evolution of experiments, their outcomes, and the scientist involved in them within High Energy Physics (HEP) at CERN—the world’s largest particle physics lab established in 1954. According to Giere, the lab is a distributed cognitive system that has continued to evolve well beyond the experiments and individuals who have worked on them over time. “In HEP, new knowledge is produced by distributed cognitive systems consisting of both humans and machines.” (p. 14). Thus, the work produced at CERN is distributed over time, comprised of multiple instruments and machines, and populated by individuals who pick up thinking where others left off about the behavior of particle physics. The system changes and matures over time, is comprised of people influencing each other’s ideas, and dedicated to the emergence of new way of thinking and understanding about a subject.

If Giere is correct in his view of the distributed cognitive system of HEP at CERN, perhaps distributed cognition is a fruitful way to think about technology-enhanced learning systems in classrooms.

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Contributor

Neil Schwartz is Professor of Psychology at California State University, Chico. He is an expert on the design and development of Web-based instructional systems, relative to graphics, metacognition, and problem solving. (Address: Neil H. Schwartz, Ph.D., Professor of Psychology, California State University, Chico, Chico, CA 95929-0234; Phone: 530.898.4968; nschwartz@csuchico.edu)

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