AI & Soc (2010) 25:83–92
DOI 10.1007/s00146-009-0264-8

ORIGINAL ARTICLE

Mind and machine: ethical and epistemological implications for research

Norm Friesen

Received: 15 October 2008 / Accepted: 9 December 2009 / Published online: 25 December 2009

Abstract Technologies are significant in research not only as instruments for gathering data and analyzing information; they also provide a valuable resource for the development of theory—in terms of what has been called the "tools to theory heuristic." Focusing on the specific example of the fields of educational psychology and instructional technology and design, this paper begins by describing how the workings of the "tools to theory heuristic" are evident in the metaphors and descriptions of behaviorism, cognitivism, and constructivism. In each of these psychological paradigms, the mind is understood in terms of a contemporaneous technological innovation: as rudimentary circuitry, as computerized data processing, and finally, in terms of information representation and visualization. The paper then argues that in applied disciplines like educational technology and human–computer interaction, technology plays two important but conflicting roles. It first operates heuristically to *explain* complex mental phenomena; it is then designed and developed explicitly as a *tool* for facilitating and developing these same complex mental processes. This paper concludes by arguing that this dual role represents an ethical dilemma—a kind of epistemological and practical "conflict of interest" in instructional technology and in related fields of systems and interface design.

Keywords Psychology · Ethics · Instructional technology · Human–computer interaction · Tools to theory heuristic

N. Friesen (✉)
Canada Research Chair in E-Learning Practices,
Thompson Rivers University, Box 3010,
900 McGill Rd., V2C 5N3 Kamloops, BC, Canada
e-mail: nfriesen@tru.ca

1 Technology and psychology: tools to theory

This paper undertakes a historical analysis of a long-standing, *metaphorical* connection between prominent technologies and conceptions of the mind, and explores its ethical implications for specific areas of research and development. The indispensible role of technological metaphors in the development of scientific theory has long been an important theme in science and technology studies. For example, using the term "epistemology engines," Ihde (2000) has traced influence of the *camera obscura* in the development of scientific epistemology; and Fox Keller (2003) has done something similar for metaphors of cybernetics and information theory in biology and genetics. My particular focus in this paper is on the way that different technologies—such as the clock, camera, and the computer—have provided powerful means specifically for understanding the *mind*. The self-sufficiency of these technologies and the certainty and detail in which their operations can be known gives their explanations of human thought and behavior special power. The suggestive power of metaphor itself also contributes to this figurative transference of properties and characteristics from the predictable operations of a technology or machine to understandings of the human mind.

In a book entitled *Metaphors of Memory: A History of Ideas about the Mind,* psychologist Douwe Draaisma provides a colorful genealogy of the metaphoric connections between technology, on the one hand, and the human mind or human memory, on the other. Draaisma shows how the history of these metaphors stretches all the way from Plato's dialogs through to the technology of the holograph:

> From Plato's wax tablet to the computers of our age, memory-related language is shot through with

> metaphors. Our views of the operation of memory are fuelled by the procedures and techniques we have invented for the preservation and reproduction of information. This influence is so strong that in, say, nineteenth-century theories on the visual memory, one can trace exactly the succession of new optical processes: in 1839 the daguerreotype and the talbotype, shortly afterwards stereoscopy, then ambrotypes and colour photography. Comparing the neuronal substratum of the visual memory to the structure of a hologram, as some of our contemporary theoreticians do, fits into a venerable tradition… The history of memory is a little like a tour of the depositories of a technology museum. (Draaisma, 2000, p. 3)

It follows that prominent technologies should not be viewed only in terms of their explicit functions, as artefacts or tools that fulfill a prescribed purpose. Instead, as Draaisma and others argue, technologies also frequently serve as *heuristics* or as practical but metaphorical means to assist in understanding the mind. Speaking specifically of the use of such technologies in scientific research, psychologist Gerd Gigerenzer describes computer and other technologies as being involved in a "tools to theories heuristic." Gigerenzer (2002) describes how "new scientific tools, once entrenched in a scientist's daily practice, suggest new theoretical metaphors and concepts" (p. 5). Using the example of cognitivism to illustrate his claim, Gigerenzer points out that it is only "*after* the [computer] became entrenched in everyday laboratory routine [that] a broad acceptance of the view of mind as a computer followed" (p. 39; emphasis added). It is only after psychologists were using computers as tools for statistical analyses in their labs, Gigerenzer explains, that they began to refer to the representation, processing, and manipulation of information as ways of accounting for thinking and learning processes.

This "tools to theory heuristic" can be restated more broadly: technologies which, at a given point and time in history, are widely used or are otherwise conspicuous have the tendency to inspire theories about the nature of the mind, memory, thinking, or learning. This paper presents the argument that the metaphorical connection between "tools" and "theory" is of significance in this way not only for psychology but (perhaps especially) for conceptions of the design and application of computer technologies in education and other fields. Using the specific example of the fields of instructional technology and design, it argues that the workings of "tool to theory heuristic" are evident in the metaphors and discourse of behaviorism, cognitivism, and constructivism. The paper then makes the case that this presents a kind of ethical dilemma for applied fields such as instructional technology and human–computer interaction (HCI). Technology in these fields functions both a way of understanding the mind *and* also as a means of facilitating mental processes. Theories of the mind, originally inspired by a given technology, are subsequently applied in these disciplines to the design and application of the same technology in a circular, self-reinforcing tautology. This introduces a kind of epistemological and practical "conflict of interest" in the fields of instructional technology and design and in related fields of systems and interface design.

2 Behaviorism: the teaching machine

Behaviorism—the first of the three psychologies or learning theories generally associated with teaching, learning, and instruction—developed rather gradually as a research program or paradigm during the first half of the twentieth century. As the name itself implies, behaviorism understands psychology in terms of the study of human and animal behavior, specifically in terms of environmental stimuli and related behavioral responses. It was established in North American universities principally through the work of J. B. Watson and E. L. Thorndike. Both of these psychologists described the relationship between stimulus and response in terms that have been characterized as resonant with or reminiscent of the technology of the telephone—a technology that was rapidly gaining in popularity at the time. Writing specifically of Watson, psychologist Ian Hutchby explains:

> Following the invention of the telephone, the psychologist Watson saw that the exchange network could act as an appropriate model for his theory of behaviour, in which the brain received incoming 'calls' from the sensory system and then relayed their 'messages' to the motor system. This tied in with Watson's behaviourist programme in psychology, in which the brain was significant only in its role as a mediator between sensations or other stimuli, and the body's responses to those stimuli. (Hutchby, 2001, p. 37)

A prominent technological innovation provides a metaphorical basis or model for a psychological paradigm: just as a call originates from one location and then is systematically routed to another, a given stimulus is received and then mediated or relayed to produce a corresponding behavioral response. (See also Edwards et al. 2002, p. 57 for a similar description of Thorndike's work and telephone exchange technology.)

By the 1950s, the dominant brand of behaviorism was B. F. Skinner's "radical behaviorism," which introduced a particularly exacting framework and set of terms for understanding behavior and also processes of learning.

Questions of learning or "behavior modification" were defined in such a rigorous and restricted way in this form of behaviorism that these activities could be neatly addressed through technological, or more specifically, *mechanical* solutions. For example, in this behaviorist vocabulary, formal learning is defined in terms of changes in voluntary behavior that are produced through programmatic "reinforcement." This reinforcement, in turn, occurs through positive consequences or changes which are introduced in the immediate environment in a manner systematically "contingent" upon behavior, leading to the expression "contingencies of reinforcement."

As a result, statements such as the following become possible: "Teaching as a technology," operates through the arrangement of "contingencies of reinforcement under which behavior changes" (Skinner 1968, p. 9). Of course, when defined in this way—as highly systematic, organized, and programed "contingencies of reinforcement"—teaching and learning turn into something that can best be undertaken through the use of relatively simple mechanical apparatus or a "teaching machine:" This kind of technology, according to Skinner, is one that is able to provide stimuli in the form of small units of information and immediate, consistent, and programed reinforcement to student responses. Linkages between stimulus and response are instantiated not literally as a telephone exchange, but with the mechanical precision and simplicity of such a technology. Moreover, teaching complex subjects—or "program[ming] complex forms of behavior" according to Skinner—simply becomes a question of "effective sequencing." "We have every reason to expect," Skinner concludes, "that the most effective control of human learning will require instrumental aid. The simple fact is that, as a mere reinforcing mechanism, the teacher is out of date." (p. 22).

The "programmed instruction movement" or "teaching machine revolution" (Saettler 2004, p. 294) that accompanied Skinner's bold pronouncements involved the use by individual students of literal teaching machines, rectangular boxes that would sit on top of students' desks. These devices would display a question in one corner of a small aperture or frame and would allow the student to write her answer in the opposite corner. "By lifting a lever on the front of the machine," Skinner explains, the student would then move "what he has written under a transparent cover and [would uncover] the correct response in the remaining corner of the frame" (1958, p. 970). The student is then able to check her response; and by again pulling a lever, she is able to record it as correct or incorrect and to move onto the next question sequenced in the machine. In keeping with Skinner's theory of stimulus, response, and reinforcement, questions presented by the machine are carefully sequenced; and only those questions answered incorrectly are shown again to the student for review.

In this way, the teaching machine provides a physical instantiation of Skinner's radical behaviorism that is striking in both its literalness and its simplicity. In doing so, the teaching machine and Skinner's instructional "revolution" set an important precedent for the psychological paradigms that followed in the wake of behaviorism. This precedent or pattern can be expressed as follows: A psychological paradigm, associated with the workings of a conspicuous technology, leads to the development of a correspondingly mechanized or "technologized" theory of learning. A similar or related technology, in turn, is then either identified or produced; and this technology is then presented and promoted as a control or solution that is the "most effective" possible for human learning.

3 The cognitive revolution

Unlike behaviorism, cognitivism arose relatively rapidly, presenting a sequence of events in the mid-1950s that has subsequently been labeled the "cognitive revolution." By the late 1960s or early 1970s, this interdisciplinary movement—initially centered in psychology, linguistics, and computer science—had all but "routed" the behaviorist paradigm in research and had established societies, journals, and university departments in its name (e.g., Thagard 2002; Waldrop 2002, pp. 140, 139). Cognitive psychology and cognitive science more generally are based on the hypothesis that the processing and representational capabilities of the computer can serve as a basis for understanding the mind:

> The expression *cognitive science* is used to describe a broadly integrated class of approaches to the study of mental activities and processes and of cognition in particular…cognitive scientists tend to adopt certain basic, general assumptions about mind and intelligent thought and behavior. These include assumptions that the mind is (1) an information processing system, (2) a representational device, and (3) (in some sense) a computer. (Bechtel & Graham 1998, xiii)

"Computational procedures," "representational structures," and "information processing" are all key to the cognitivist paradigm (e.g., Boden 2006; Thagard 2002) and also to its role in instructional technology design and development.

The heuristic or metaphorical significance of new technologies in this paradigm is obvious: By the end of Second World War and during the years immediately following, computers were a novel and conspicuous technology, often discussed in the popular press in terms of "giant brains" or "machines that think" (e.g., Edwards 1997, pp. 146, 190–196). Especially in the first years of the cognitive movement, the computer and computer programs were seen as providing nothing less than an "existence proof" for particular cognitive components and models of mental operation. Conjectures about how we carry out cognitive tasks—for example, how we recognize faces or sounds, or how we remember or solve problems—were seen as being "provable" by being computationally modeled. If it were possible to get a computer to accomplish the same kinds of mental tasks that people do, it would seem reasonable to conclude that our minds accomplish the same task in the same way. As the next part of this paper will show, this rather "literal" application of the computational metaphor (or "tool to theory heuristic") continues to play an important part in current cognitivist and constructivist understandings in instructional technology and related disciplines.

It is relatively easy to see how cognitivism provides a very different set of terms and concepts for learning and teaching than behaviorism does. Indeed, from the 1960s to the present day, the "cognitive revolution" can be said to have redefined all of the key concepts in educational research: Learning itself is defined not as behavioral change, but in terms of the way information is represented and structured in the mind (e.g., Ausubel 1960; Craik and Lockhart 1972; Miller 1956; Piaget and Inhelder 1973). Teaching is no longer conceptualized as the modification of behavior through contingencies of reinforcement, but is instead seen as the support of "active processing," of the effective construction of mental representations (Scardamalia and Bereiter 2003; Wolfe 1998). With thought, perception, and learning processes, all understood in terms of information processing or symbol manipulation, the computer is seen as being able to act cognitively with or in support of the student or learner. The computer therefore is cast as a kind of "cognitive technology" (Pea 1985), a "cognitive tool" (Kozma 1987; Jonassen and Reeves 1996), or simply, a "mindtool" (Lajoie 2000; Jonassen 2006) that is uniquely suited to support the cognitive tasks involved in learning: "To be effective, a tool for learning must closely parallel the learning process; and the computer, as an information processor, could hardly be better suited for this" (Kozma 1987, p. 22). Computer technology is seen in this context specifically as being capable of "evok[ing] necessary operations and compensate[ing] for capacity limitations" in human cognitive functioning (Kozma 1987, p. 23), with some functions being especially suited to this type of compensation:

> there are three aspects of the learning process that are primary considerations in designing computer-based learning: the limited capacity of short-term or working memory, the structure of knowledge in long-term memory, and the learner's use of cognitive strategies. (Kozma 1987, p. 22)

Such an understanding of the role of the computer coincides closely with "computer-based instruction" (CBI), which, as one historical account explains, developed directly from the "examin[ation of] learning as a function of the processing performed by the learner" (Szabo 1994). Above all, it was the computer's working memory that was seen in CBI as being capable of interacting with the short-term memory of the learner. Through drill-and-practice, tutorial and simple simulation activities, the computer was seen as being able to "communicate information in ways which would avoid" reaching the limits of the learner's "short-term memory" (Szabo 1994).

In this way, the computer is given a role in education that is remarkably similar to its function in military "man–machine" systems described in the early literature of cybernetics and cognitivism. The computer and the user are seen to form a single "operating unit, [with] the human operator [acting as] an information transmitter and processing device interposed between his machine's displays and their controls" (Lachman et al. 1979, p. 58). The computer is understood as "working in intimate partnership," in symbiotic or dyadic relationship "with the [human] learner," acting to "share," "extend," and "amplify" (Jonassen 2000) his or her cognitive capacities:

> Learners and technologies should be intellectual partners in the learning process, where the cognitive responsibility for performing is distributed to the part of the partnership that performs it best. (Jonassen, Peck & Wilson, 1999, p. 13; quoted in McLoughlin & Luca, 2001; Kim & Hay, 2005)

As the ongoing use of this quote indicates, this conception of human and computer "partnership" is one that has had currency for more than two decades, with the same terms ("cognitive tool," "mindtool") and frames of reference (human–computer "partnership") being utilized with remarkable consistency up to the present day (e.g., see also Keengwe et al. 2008; Dror and Harnad 2008).

4 Cognitivism to constructivism: AI in reverse

Over this same period of time, however, slightly different descriptions of the close interaction between learner and computer also emerged. These descriptions are neither purely cognitivist nor are they reducible ways of thinking that could be called "constructivist;" instead, they might be best described as a kind "cognitive-constructivist" hybrid. Constructivism in this context refers to a theory of learning which sees learning as an active epistemological process of construction in which the student and her past experiences play a significant role. The emergence of constructivist influences in otherwise explicitly cognitivist scholarship can be briefly illustrated by looking at the history of the phrase, "AI in reverse."

This phrase was originally introduced in Gavriel Salomon's influential and widely referenced paper, "AI in

Reverse: Computer Tools that Turn Cognitive" (Salomon 1988; see also Kozma 1991; Dillenbourg 1996; Bonk and Cunningham 1998; Jonassen 2003; Jonassen 2005). In it, Salomon explains this titular "reversal" of AI as follows:

> The purpose of applying AI to the design of instruction and training is basically to communicate with learners in ways that come as close as possible to the ways in which they do or ought to represent the new information to themselves. One expects to save the learners, so to speak, unnecessary cognitive transformations and operations. (pp. 123–124)

The computer in this case has a slightly different relationship to the mental processes than one of partnership, compensation, or augmentation. This new and different relationship is based on the constructivist notion that cultural artifacts or tools affect the mind in ways that are much more profound than merely augmenting its processing or memory functions. This way of thinking is based on Lev Vygotsky's proposal that linguistic signs or symbols are not simply neutral carriers of information but that they act as "instrument[s] of psychological activity in a manner analogous to the role of [tools] in labor" (Vygotsky 1978, p. 52). Like tools of physical labor, "cognitive" tools—from primitive linguistic symbols to computers as powerful "symbol manipulators"—can help form and shape the fundamental character of the laborer or tool user. The "primary role for computers" in educational technology then becomes one not simply of mirroring or augmenting cognitive operations but of fundamentally "reorganizing our mental functioning" (Pea 1985, p. 168). Computers are still seen as working in intimate partnership with the learner but their principle contribution is not the augmentation of human intelligence but its exemplification or *modeling*:

> rather than having the computer simulate human intelligence [the idea is to] get humans to simulate the computer's unique intelligence and come to use it as part of their cognitive apparatus (Jonassen 1996, 7).

In this sense, computational "mindtools" can be understood as "AI in reverse," with the ultimate goal of making human cognitive operations as efficient and effective as those engineered and tested for computers.

5 Constructivism: representation and verification

As is illustrated by the use of the phrase "AI in reverse," constructivist understandings of technology-enabled learning emerged very gradually from cognitive discourse, appearing as far back as the mid-1980s. The history of this phrase illustrates that a very fluid, even porous boundary separates constructivism from cognitivist principles. To gain a fuller appreciation of the role of constructivism in instructional technology and related disciplines, however, it is important to note that the term "constructivism" itself is often considered to be notoriously vague, with quite different meanings and implications in philosophy and sociology, for example, than in instructional technology and design. Although the origin of constructivism is not directly traceable to a single technology or innovation, the birth of cybernetics—the study of both human and machine as systems of command and control—gave significant impetus to the development of constructivism in the latter part of the twentieth century. Also, the close connection between cognitivism and constructivism has given rise to visions of technology use in instructional technology that are very similar to those described earlier. (In many cases, the only difference is that the sophistication of the technology, and the complexity of the learning processes is significantly expanded or amplified.)

For instructional technology and learning theory generally, the principle contribution of constructivism is its emphasis on the active "construction"—rather than the passive reception or acquisition—of students' knowledge. It is the activity of such construction, and the complex processes through which it occurs, that are front and center in definitions of the term "constructivism" in the fields of instructional theory and technology. Duffy and Cunningham, for example, define constructivism in terms of two closely interrelated propositions: "that (1) learning is an active process of constructing rather than acquiring knowledge, and (2) [that] instruction is a process of supporting that construction rather than communicating knowledge" (Duffy and Cunningham 1996, p. 171). David Jonassen, a name associated with both cognitivist (e.g., Jonassen et al. 1989) and constructivist (e.g., Jonassen et al. 1999) approaches, explains:

> Succinctly, constructivism avers that learners construct their own reality or at least interpret it based on their perceptions of experiences, so an individual's knowledge is a function of one's prior experiences, mental structures, and beliefs that are used to interpret objects and events. […] What someone knows is grounded in perception of physical and social experiences which are comprehended by the mind. What the mind produces are mental models that represent what the knower has perceived. (Jonassen, 1994, pp. 34–35)

As Jonassen's definition makes clear, the range of possible constructions of knowledge allowed by constructivism to account for a given "reality" can be quite wide or varied. This has led to the objection that as a learning theory, constructivism tends toward to a kind of criterionless "subjectivism" or "relativism" (Duffy and Cunningham 1996, p. 171): if knowledge of the world is constructed rather than objectively given, the argument goes, "[a]nyone's constructions are as good as anyone else's and… we are unable to judge the value or truth of constructions with any degree of certainty" (Duffy and Cunningham 1996, p. 171). Constructivists deal with this objection, however, by saying that just because knowledge cannot be judged in terms of absolute truth or certainty, it can always be evaluated in terms of its practical *viability*. Knowledge can be validated, in other words, "by testing the extent to which it provides a workable, acceptable action relative to potential alternatives" (Duffy and Cunningham 1996, p. 171). This viability, moreover, is seen as being "testable" through both individual and collaborative processes and in terms of a rather wide range of methods and techniques. Propositions or hypotheses, as one example, can be verified or falsified in collaborative learning through reference to new, previous, or shared experience (e.g., Scardamalia and Bereiter 2003; Hoadley 2005); problem-solving and "self-regulatory" strategies, as a second example, can be verified and refined based on how fully they address the problem or cognitive challenge at hand (e.g., Perry and Winne 2006; Mayer and Wittrock 2006); and learner (or "novice") constructions, mental models or interpretations, can be compared with those of professionals or specialists, and brought into closer alignment with these "expert" constructions (e.g., Bransford et al. 2000, pp. 31–50).

It is in connection with the specific processes involved in the construction and verification of knowledge—its representation, testing, and refinement—that computers and Internet technologies become important in constructivist accounts of instruction. These constructivist computational functions, however, are more demanding than those required of this technology by earlier, cognitivist conceptions of computer-supported learning. In the case of constructivism, as Perkins explains, the computer's "information processor must be seen *not just* as shuffling data" between one component (e.g., the learner) and another (e.g., a computer's memory). Instead, Perkins continues, this same technology must be seen as "wielding" data much more "flexibly during learning—making hypotheses, testing tentative interpretations, and so on." (Perkins 1991, p. 21, emphasis added). In constructivism, in other words, the computer's educational value does not derive so much from the simple processing and storage of data, but rather, through more advanced or higher-level computational functions such as representation, distribution, mapping, and verification. Correspondingly, both human and computer are seen as operating on the level of "knowledge" and its "construction" rather than of "data" and its "processing" (although references to data or information and its processing still remain evident in constructivist educational discourse).

In constructivism, learning is conceptualized in terms of the development or representation of both rudimentary (i.e., learner or novice) knowledge constructions and their gradual development into more intricate and refined (i.e., expert) constructions. Such representations, moreover, are associated with terms like cognitive "schemas," "models," and "structures." In this context, the contribution of Internet and computer technologies is understood in terms of the provision of multiple means of representing and refining these schemas or structures. Take for example the notion of the "visualization" of cognitive structures: the educational contribution "of interactive multimedia, animation, and computer modeling technologies" in education has been defined specifically in terms of the "representational affordances" they provide (Jacobsen 2004, p. 41). These representational affordances are of value particularly because they allow for the "dynamic qualitative representations of the mental models held by experts and novice learners" to be visualized and easily compared (Jacobsen 2004, p. 41). And this in turn allows for the gradual approximation of novice models or schemas to those of more expert constructors of knowledge (Bransford et al. 2000). Similar analogies or arguments have been made in the case of other representational capabilities of the computer: from hypertext and hypermedia (e.g., Jonassen 1989) and computer-supported collaborative learning environments (e.g., Hoadley 2005) to more interactive and kinesthetic forms of games and simulations (e.g., Gee 2007). In each case, it is the ability of advanced computer technologies to represent and distribute knowledge—and thus make "normally hidden knowledge processes [or representations]… transparent to users" (Scardamalia 2003 p. 23)—that is the principle source of its instructional value.

Like behaviorism and cognitivism before it, constructivism is used in instructional technology and related discourses to assign terms to thinking that are derived from or at least clearly consonant with the functions of a computer. Instead of connections between stimulus and response or the ability to process raw information, it is the computer's capacity for the representation of mental structures and the mirroring of self-regulatory, problem-solving, and other rule-based functions that is presented as the source of its potential as a powerful pedagogical technology.

6 A conflict of practical and theoretical interests

Constructivism, like cognitivism and behaviorism before it, gives vivid illustration to the importance of technologies as metaphors in psychology and learning theory. Together, these three psychologies provide much support for the "tool to theory heuristic" outlined earlier. In each case, consecutive technological innovations form the basis for successive understandings of the human mind. The development of information and communication innovations in the twentieth century can be traced in recent psychological theories much as Draaisma describes photographic technologies of the nineteenth century as finding expression in theories of memory of that same age: from the telephone exchange as a central relay for inputs and outputs comes behaviorist stimuli and response; from the computer as a symbol manipulator comes the mind as an information processor; and from the computer as a networked, multimedia device come constructivist notions of processes of the dynamic representation and verification of knowledge.

In outlining the notion of a "tool to theory heuristic" and in emphasizing the importance of technological metaphors in psychology, this paper is *not* seeking to diminish the value or importance of psychology's many lasting contributions to instruction. It is not arguing, for example, against the value of constructivist scaffolding, of cognitivist advanced planners, or the provision of "positive reinforcement" for good behavior. The issue here is not the practical value of these approaches, but rather, their theoretical and paradigmatic grounding.

This paper argues that disciplines which focus on the design of computer systems through the application of human psychology are doubly implicated in their relation to technology. Technology not only serves a heuristic function as a metaphor for the mind, it also clearly serves as the principle focus to which this metaphorically derived knowledge is applied. Besides providing an explanation for mental processes, computer technology is *also* the principle means for supporting, refining, and developing these same processes. For example, all phenomena of essential concern in the discipline of HCI can be subsumed to a single vocabulary of algorithmic rule-bound action and interaction:

> Human–computer interaction (HCI) is fundamentally an information-processing task. In interacting with a computer, a user has specific goals and subgoals in mind. The user initiates the interaction by giving the computer commands that are directed toward accomplishing those goals. The commands may activate software programs designed to allow specific types of tasks, such as word processing or statistical analysis to be performed. (Proctor and Vu, 2008, p. 44)

In this case, as in the case of instructional technology, the operations of both user and computer operations are defined in terms of data processing or other technological processes. This gives these applied disciplines a self-referential, self-reinforcing tautological circularity which is problematic.

Interestingly, writing earlier in the field of HCI, Card, Moran and Newell (1983) explicitly acknowledge this self-reinforcing self-referentiality. Echoing Kozma's roughly contemporaneous affirmation of the computer as paralleling and thus as being uniquely suited to support "the learning process," they say

> It is natural for an applied psychology of human–computer interaction to be based on information-processing psychology, with the latter's emphasis on mental mechanism… Since the system designer also does his work in information processing terms, the emphasis is doubly appropriate. (p. 13)

The information processing of the designer, user, learner, and machine mutually reinforce one another in a manner that is here deemed "natural." The image of efficient information processing, in other words, is mirrored back and forth, between the user and the interface, the learner and cognitive tool, and even the designer and the system being constructed. "[H]aving conceived of thinking as a kind of machinery," as Andrew Feenberg puts it, "machinery in fact turns out to be the perfect image of the process of thought" (2002, p. 97), and this image then also serves as a model for the system, the user, the designer, and the student.

This "image of thought" passes between tool and learner and between machinery and theory; and this image is recognized at various points in this process as a potent technology, a theory of mind, and a powerful mental affordance. In behaviorism, for example, the image of reinforcing "circuits" or mechanistic connections between stimulus and response is transferred from the then conspicuous technology of the telephone exchange to a theory of behavior and then back to its pedagogical treatment in the form of the mechanical reinforcement programed in Skinner's "teaching machine." In the case of cognitivism and constructivism, the computer and its proliferating capabilities serve first as a model for human mental tasks and then as an indispensable mechanism for their support.

Once the initial comparison between mind and machine has been operationalized in psychology, its original, metaphorical, or hypothetical nature is all too readily repressed or forgotten in related, applied disciplines. Forgetting that thinking was originally and provisionally conceived as a kind of machinery, this same machinery then reappears as the perfect image of thought, as a support which "could hardly be better suited" (Kozma 1987, p. 22) for the cognitive tasks in question.

Speaking specifically of the metaphoric roles of computer technology in psychology and AI, Derek Edwards explains:

> Metaphors [of this kind] join two discourse domains together, and the effects are mutual. They illuminate,

> draw attention to, points of contrast and similarity, generality and exception, that might otherwise be missed. What is dangerous is when the metaphorical nature of the enterprise is forgotten, and domain A is talked about in terms of domain B, as if it were not a metaphor at all. (Edwards 1997, 31)

In this case, "domain A" refers to applied design fields like instructional technology and HCI, and "domain B" is cognitive and constructivist psychology. The hypothetical, paradigmatic grounding of one field is neglected when its central understandings are transferred into the context of another. The metaphorical terms from the psychological domain are literalized or reified in their use in fields of applied design and development. As this paper has shown, the importance of technological metaphors in systematic considerations of the mind is not some happy accident in which psychological theory and prominent technologies just happen to coincide. It is instead been a pattern that has repeated with remarkable consistency throughout the history of psychological research.

In the particular case of the applied disciplines of educational technology and HCI, the repetition of this pattern is especially problematic. For these applied fields have much to gain from the self-reinforcing circularity of this pattern. First, it provides them with a ready argument for the efficacy of their technological design and development priorities. Second, and going even further, this tautological reinforcement means that these fields are able to greatly elevate the status of the technologies and solutions they develop. These artifacts and techniques are no longer mere devices or means to an end, but can be presented as intrinsically epistemological or cognitive in nature, as machines that embody the distilled essence of instruction, cognitive processing, or knowledge construction. In this way, the practical interests of these fields of applied research and development are very well served.

On the other hand, the priorities and interests of theoretical development, of the paradigmatic grounding and definition of both "pure" as well as applied disciplines, are not so well supported. These priorities and interests are related to matters such as logical rigor and consistency, and a clear understanding of the derivation and adequacy of paradigms, ideas, and hypotheses. Central to these interests, for example, is the question of the nature and implications of the initial, heuristic comparison between mind and machine in psychology. Also important for these interests is the matter of the explanatory adequacy of such a comparison, and the question as to whether factors *other* than explanatory power may be motivating it.

Given the difference between theoretical interests and the overtly pragmatic interests described earlier, grounding for the claim that there may be a conflict of interest presented by the dual role of technologies in fields such as instructional technology and HCI becomes clear. And this conflict of interest, in turn, represents an ethical challenge to the disinterested development of these disciplines and the testing and application of related theory.

7 Conclusion

An antidote to this problematic situation would be provided by the recognition of fundamental differences between thought and technology, both in psychological explanations and in technical applications. In both education and HCI, the difference between human thought and action and computational operation is given consistent and systematic emphasis in approaches such as action theory (e.g., Engeström 1987; Kaptelinin and Nardi 2006) and ethnomethodology (e.g., Dourish 2001). Both of these approaches understand human thought and action as being culturally, historically, politically, and situationally contingent, as being shaped by human factors that extend well beyond those accounted for through cognitive architectures or variations in learning styles. Ethnomethodology in particular emphasizes the emergent, fundamentally improvisatory nature of collective and individual human action and has been used in HCI by Kaptelinin and Nardi, Dourish and others, and in education by Roth (2007) and Koschmann et al. (2007), to provide only a few examples.

The fundamental differences between thought and technology can also be brought to attention by reconsidering definitions of technology itself. In instructional technology research, technology has frequently been defined as "the systematic application of scientific or of organized knowledge to practical tasks" (from Galbraith 1967, p. 12; quoted in Saba 1999; Saettler 2004; Abdelraheem 2005; Januszewski and Molenda 2008). As such, this definition portrays technology as the rational embodiment of organized, scientific knowledge and as a direct expression of scientific progress and of the researcher's contribution to it. This definition leaves little room for an understanding of other, less explicitly rational and controllable aspects of technology and their relationship to knowledge and research. The discussion of the "tools to theory heuristic" at the outset of this paper provides an illustration of at least one of these other less controlled or explicitly rational aspects. It shows how conspicuous technological innovations can inspire new understandings of the mind in psychology and in research into human memory. In this context, technology is clearly something more than an expression of scientific knowledge, hard won through the accumulation of systematic research. Technology is instead something that also shapes and influences research. By providing powerful metaphors for understanding epistemology and the mind, computer and other technologies exercise a historical, cultural, discursive influence on scientific and organized knowledge. Recognition of this contribution of technology, too, would provide important antidote to the epistemological "conflict of interest" identified earlier, ultimately leading research in instructional technology and other disciplines to firmer theoretical or paradigmatic grounding.

References

Abdelraheem AY (2005) Integrating instructional technology with information technology and its implications for designing electronic learning systems. Int J Instr Media 32(2):125–133

Ausubel DP (1960) The use of advance organizers in the learning and retention of meaningful verbal material. J Educ Psychol 51:267–272

Bechtel W, Graham G, Abrahamsen A (1998) Preface. In: Bechtel W, Graham G (eds) A companion to cognitive science. Basil Blackwell, Oxford, pp xiii–xvi

Boden MA (2006) Cognitive science. Encyclopedia of philosophy, 2nd edn, vol 2. Thompson Gale, Farmington Hills, pp 296–301

Bonk C, Cunningham DJ (1998) Searching for learner-centered, constructivist, and sociocultural components of collaborative educational learning tools. In: Bonk C, King K (eds) Electronic collaborators: learner-centered technologies for literacy, apprenticeship, and discourse. Lawrence Erlbaum Associates, Mahwah, NJ

Bransford JD, Brown AL, Cocking RR (eds) (2000) How people learn: brain, mind, experience and school. National Academy Press, Washington, DC

Craik F, Lockhart R (1972) Levels of processing: a framework for memory research. J Verbal Learn Verbal Behav 11:671–684

Dillenbourg P (1996) Distributing cognition over brains and machines. In: Vosniadou S, De Corte E, Glaser B, Mandl H (eds) International perspectives on the psychological foundations of technology-based learning environments. Lawrence Erlbaum, Mahwah, NJ

Dourish P (2001) Where the action is: the foundations of embodied interaction. MIT Press, Cambridge, MA

Draaisma D (2000) Metaphors of memory: a history of ideas about the mind. Cambridge UP, Cambridge, UK

Dror I, Harnad S (2008) Offloading Cognition onto Cognitive Technology. In: Dror IE, Harnad S (eds) Cognition distributed: how cognitive technology extends our minds. John Benjamins, Amsterdam

Duffy TM, Cunningham DJ (1996) Constructivism: Implications for the design and delivery of instruction. In: Jonassen DH (ed) Handbook of research for educational communications and technology. Simon & Schuster Macmillan, New York, pp 170–198

Edwards PN (1997) The closed world: computers and the politics of discourse in cold war America. MIT Press, Cambridge, MA

Edwards A, Gilroy P, Hartley D (2002) Rethinking teacher education: collaborative responses to uncertainty. Routledge Falmer, London

Engeström Y (1987) Learning by expanding: an activity—theoretical approach to developmental research. Accessed 24 Sept 2008 from: http://communicationucsdedu/MCA/Paper/Engestrom/expanding/tochtm

Feenberg A (2002) Transforming technology: a critical theory revisited. Oxford UP, Oxford

Fox Keller E (2003) Marrying the Premodern to the Postmodern: Computers and Organisms After WWII. In: Tofts D, Jonson A, Cavallaro A (eds) Prefiguring cyberculture: an intellectual history. University of California Press, Berkeley, pp 52–65

Galbraith JK (1967) The new industrial state. Houghton Mifflin, Boston

Gee JP (2007) Video games and embodiment. Accessed 30 Aug 2008 from: http://inkido.indiana.edu/aera%5F2007/

Gigerenzer G (2002) Adaptive thinking: rationality in the real world. Oxford UP, Oxford

Hoadley CM (2005) Design-based research methods and theory building: a case study of research with speakeasy. Educ Technol 45(1):42–47

Hutchby I (2001) Conversation and technology: from the telephone to the internet. Polity, London

Ihde D (2000) Epistemology engines. Nature 406(July 6):21

Jacobsen M (2004) Cognitive visualizations and the design of learning technologies. Int J Learn Technol 1(1):40–62

Januszewski A, Molenda M (eds) (2008) Educational technology: a definition with commentary. Lawrence Erlbaum Associates, New York

Jonassen DH (1989) Hypertext/hypermedia. Educational Technology Publishers, Englewood Cliffs, NJ

Jonassen DH (1994) Thinking technology: toward a constructivist design model. Educ Technol 34(4):34–37

Jonassen DH (1996, 2000) Computers as mindtools for schools: engaging critical thinking. Prentice-Hall, Upper Saddle River, NJ

Jonassen DH (2003) Using cognitive tools to represent problems. J Res Technol Educ 35(3):362–381

Jonassen DH (2005) Modeling with technology: mindtools for conceptual change, 3rd edn. Prentice-Hall, Columbus, OH

Jonassen DH (2006) Modeling with technology: mindtools for conceptual change. Merrill/Prentice-Hall, Columbus, OH

Jonassen DH, Reeves TC (1996) Learning with technology: Using computers as cognitive tools. In: Jonassen DH (ed) Handbook of research on educational communications and technology. Macmillan, New York, pp 693–719

Jonassen DH, Hannum WH, Tessmer M (1989) Handbook of task analysis procedures. Praeger, New York

Jonassen DH, Peck KL, Wilson BG (1999) Learning with technology: a constructivist perspective. Merrill, Upper Saddle River, NJ

Kaptelinin V, Nardi B (2006) Acting with technology: activity theory and interaction design. MIT Press, Cambridge, MA

Keengwe J, Onchwari G, Wachira P (2008) The use of computer tools to support meaningful learning. Assoc Advance Comput Educ J 16(1):77–92

Kim B, Hay KE (2005) The evolution of the intellectual partnership with a cognitive tool in inquiry-based astronomy laboratory. In: Koshmann T, Suthers DD, Chan T-W (eds) Proceedings of the 2005 conference on Computer support for collaborative learning: learning 2005: the next 10 years. ACM, New York

Koschmann T, Stahl G, Zemel A (2007) The video analyst's manifesto (or the implications of Garfinkel's policies for studying instructional practice in design-based research). In: Goldman R, Pea R, Barron B, Denny SJ (eds) Video research in the learning sciences. Lawrence Erlbaum, Mawah, NJ

Kozma RB (1987) The implications of cognitive psychology for computer-based learning tools. Educ Technol 27(11):20–25

Kozma RB (1991) Learning with media. Rev Educ Res 61(2):179–211

Lachman R, Lachman JL, Butterfield EC (1979) Cognitive psychology and information processing. Lawrence Erlbaum Associates, Hillsdale, NJ

Lajoie SP (ed) (2000) Computers as cognitive tools (volume 2): no more walls. Lawrence Erlbaum Associates, Mahwah, NJ
Mayer RE, Wittrock MC (2006) Problem solving. In: PA Alexander, PH Winne (eds) Handbook of educational psychology, 2nd edn. Lawrence Erlbaum, Mahwah, pp 287–303
Miller GA (1956) The magical number seven, plus or minus two: some limits on our capacity for processing information. Psychol Rev 63:81–97
Pea RD (1985) Beyond amplification: using computers to reorganize human mental functioning. Educ Psychol 20:167–182
Perkins DN (1991) Technology meets constructivism: do they make a marriage? Educ Technol 31(5):18–23
Perry N, Winne P (2006) Learning from learning kits: Gstudy traces of students' self-regulated engagements with computerized content. Educ Psychol Rev 18(3):211–228
Piaget J, Inhelder B (1973) Memory and intelligence. Basic Books, NewYork
Roth W-M (2007) Doing teacher-research: a handbook for perplexed practitioners. Sense Publishers, Rotterdam
Saba F (1999) Technology and tradition: complementary or contradictory concepts? TechTrends 34(1):31–33
Saettler P (2004) The evolution of American educational technology. Lawrence Erlbaum Associates, Mahwah, NJ
Salomon G (1988) AI in reverse: computer tools that turn cognitive. J Educ Comput Res 4(2):123–139
Scardamalia M (2003) Knowledge forum (Advances beyond CSILE). J Distance Educ 17 (Suppl. 3 Learning technology innovation in Canada): 23–28
Scardamalia M, Bereiter C (2003) Knowledge building in the encyclopedia of education, 2nd edn. Macmillan Reference, New York, USA, pp 1370–1373. Also available online: http://ikitorg/fulltext/inpressKBpdf
Skinner BF (1958) Teaching machines. Science 128(3330):969–977
Skinner BF (1968) The technology of teaching. Appleton-Century-Crofts, New York
Szabo M (1994) Enhancing the interactive classroom through computer based instruction: some examples from PLATO. Computer-mediated communications and the online classroom vol I. Hampton Press, Cresskill, NJ
Thagard P (2002) Cognitive science Stanford encyclopedia of philosophy. http://platostanfordedu/entries/cognitive-science/
Vygotsky LS (1978) Mind and society: the development of higher mental processes. Harvard UP, Cambridge, MA
Waldrop MM (2002) The dream machine: JCR Licklider and the revolution that made computing personal. Penguin Books, New York
Wolfe P (1998) Revisiting effective teaching. Educ Leadersh 56(3):61–64