Chapter 1

What are Cognitive Tools?

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1 Tools

Tools are extensions of human beings that partially differentiate humans from lower order species of animals. Other species of animals have discovered tools, but have been unable to conceive needs to construct tools or incorporate tools into their cultures. Throughout history, humans have developed mechanical tools to facilitate physical work. The wheel and lever provided humans with an enormous mechanical advantage. The industrial revolution added artificial sources of power to extend that advantage. The electronic or information revolution has further extended that advantage by extending the functionality and speed of tools. Computers now perform tasks at speeds which are orders of magnitude greater than humans with or without more primitive tools were capable of.

Tools have been created for many purposes. They have typically evolved from functional needs — hunting, farming, constructing, transporting, calculating, transmitting and so on. Mechanical tools were developed to facilitate physical needs. The bow and spear were developed as tools for hunting, the plough for tilling the soil, the wrench and bolt for fastening things together. Steam driven machinery was developed in the last century to support the manufacture and transport of products. The computer was developed in this century for calculating, storing and communicating information. Each technological revolution has generated increasingly more sophisticated tools with greater functionality. Often, as tools become more powerful in solving mechanical problems, their functionality narrows (can you think of any other application of a cotton gin than its intended one?). Electronic technologies, including the computer, have provided multiple information processing functions. Many of the software tools developed for the computer also have extensibility, that is, they can change forms and assume additional functionality. This book is about developing and adapting computer-based tools to extend cognitive functioning during learning.

The irony of education is that few tools have ever been designed or executed to facilitate learning. The chalk board is one of the few notable exceptions, particularly in light of its popularity and longevity. Other tools, such as pencils, paper, calculators, have become important to education. Many tools and media such as projectors, transmitters, and computers have been

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retroactively adapted to educational purposes, however few have been developed with learning as a goal.

This book is about learning tools — computer-based tools that have been adapted and/or developed to support learning. These tools are different from normal, task-specific tools. These are generalisable tools that can facilitate cognitive processing — hence cognitive tools. Just as a convection oven supports the cooking process, cognitive tools support the learning process. Derry (1990) defines cognitive tools as both mental and computational devices that support, guide, and extend the thinking processes of their users. Many cognitive tools, such as cognitive and metacognitive learning strategies (Tessmer & Jonassen, 1988), are internal to the learner. However, the tools described in this book are external, computer-based devices and environments that extend the thinking processes of learners. These are tools that are used to engage learners in meaningful cognitive processing of information. They are knowledge construction and facilitation tools that can be applied to a variety of subject matter domains. These cognitive tools include specially designed knowledge construction tools, such as semantic networking tools and microworlds for mediating learning. Much of the book focuses on the use of application tools, such as expert systems and hypertext, for engaging cognitive processing and mediating learning. In order to explain conceptually how cognitive tools work, we next consider the mediation of learning.

2 The Mediation of Learning

Technologies do not directly mediate learning. That is, people do not learn from computers, books, videos, or the other devices that were developed to transmit information. Rather, learning is mediated by thinking (mental processes). Thinking is activated by learning activities, and learning activities are mediated by instructional interventions, including technologies. Learning requires thinking by the learner. In order to more directly affect the learning process, therefore, we should concern ourselves less with the design of technologies of transmission and more with how learners are required to think in completing different tasks. Rather than developing ever more powerful teaching hardware, we should be teaching learners how to think more effectively. We should focus less on developing sophisticated multi-media delivery technologies and more on thinking technologies, those that engage thinking processes in the mind. The role of delivery technologies should be to display thinking tools, tools that facilitate thinking processes.

Cognitive tools, if properly conceived and executed, should activate cognitive and metacognitive learning strategies. They are computationally based tools that complement and extend the mind. They engage generative processing of information. Generative processing occurs when learners assign meaning to new information by relating it to prior knowledge (Wittrock, 1974). Deeper information processing results from activating appropriate schemata, using them to in-

terpret new information, assimilating new information back into the schemata, reorganising them in light of the newly interpreted information, and then using those newly aggrandised schemata to explain, interpret, or infer new knowledge (Norman et al, 1978). Knowledge acquisition, according to these definitions, is a constructive process. Cognitive tools facilitate the processes of constructing knowledge by learners. They are knowledge construction tools — tools that extend the mind.

This workshop was about cognitive tools — computer-based tools that facilitate generative processing of information by learners. Cognitive tools represent learning *with* information processing technologies as opposed to learning *of* them (Salomon, Perkins & Globerson, in press). Learning *with* technologies amplifies the learner's cognitive processes while using those technologies. Computer-based cognitive tools are in effect cognitive amplification tools that are part of the environment. Environments that employ cognitive tools distribute cognition to the person (Perkins, 1990). Cognitive tools are intelligent resources with which the learner cognitively collaborates in constructing knowledge.

3 Epistemological Basis for Cognitive Tools

The paradigm shift in learning psychology from behaviourism to cognitivism is well documented and seldom disputed as a step forward in learning theory. Generative learning assumes that the mind is necessary for learning and is responsible for knowledge acquisition through the engagement of cognitive processing by the learner. In this conception, knowledge is distinguished from information. Information is the stimuli that are perceived and recorded by the mind. Cognitive learning theory assumes that learners interact with that information, interpret it, and build personal knowledge representations after relating that information to their prior knowledge. The information with which learners construct their reality represents the external reality. However, this information itself does not represent knowledge.

Traditional, materialistic conceptions of mind (objectivism) view thinking and learning quite differently. Objectivism treats knowledge as externally mediated information which is generated by a teacher and transmitted to learners. The purpose of education is for the learner to acquire the knowledge of the teacher — to assimilate the knowledge of the teacher or expert. Objectivism equates information and knowledge as far as the learner is concerned. Knowledge, according to an objectivist epistemology, is determined by the teacher and not the learner. There is an external reality that each individual can come to know in the same way. Knowledge is externally referenced rather than internally generated.

Cognitive tools are are based upon a constructivist epistemology. The goals and design of constructivistic technologies differ from previous technological innovations (Figure 1). Traditional technologies such as programmed instruction and techniques such as instructional design are

objectivistic. That is, their intention is to transmit objective knowledge. Programmed instruction was both objectivistic and behavioristic. External reality was mapped onto learners by manipulating their behavioural patterns. Although instructional design is in transition from behavioristic to cognitivistic assumptions and techniques, it too remains objectivistic. Even the most advanced, computer-based learning technologies, such as intelligent tutoring, are largely objectivistic. Although intelligent tutors make cognitive assumptions about the learning process, they still assume that the expert's knowledge structure is mapped onto the student's. Tools that amplify thinking and facilitate knowledge construction can be thought of as constructivistic tools.

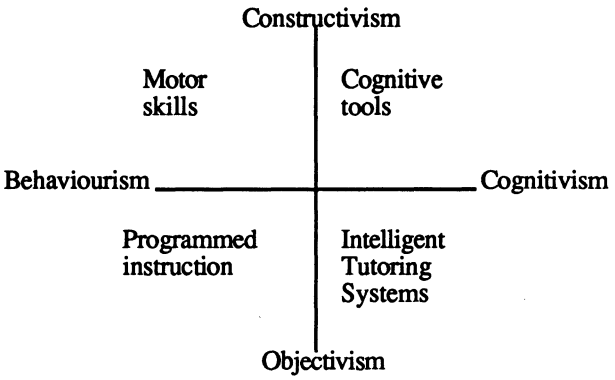

Figure 1 The goals and design of constructivistic technologies

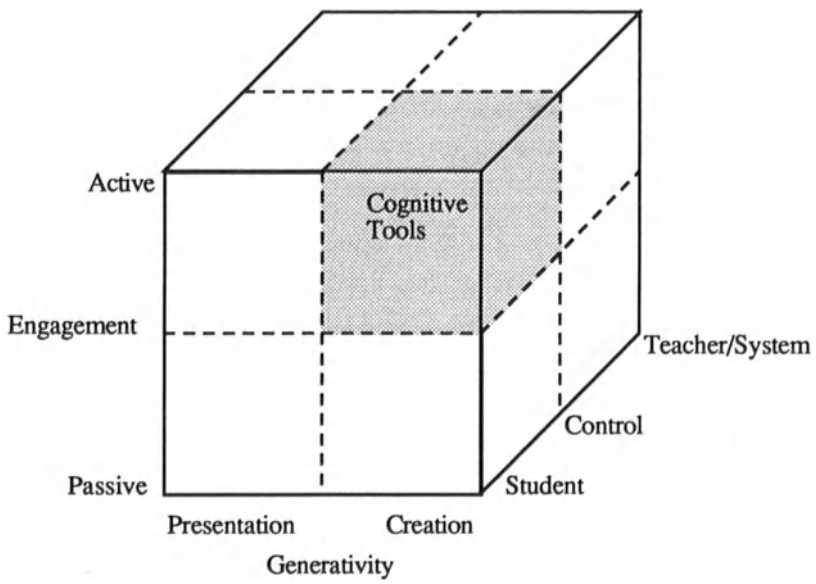

Figure 2 Cognitive tools

Cognitive tools are constructivistic because (as shown in Figure 2) they actively engage learners in creation of knowledge that reflects their comprehension and conception of the information rather than focusing on the presentation of objective knowledge.

Cognitive tools are learner controlled, not teacher or technology-driven. Cognitive tools are not designed to reduce information processing, that is, make a task necessarily easier, as has been the goal of instructional design and most instructional technologies. Nor are they "fingertip" tools (Perkins, 1990) that learners use naturally, effortlessly, and effectively. Rather cognitive tools provide an environment and vehicle that often requires learners to think harder about the subject matter domain being studied while generating thoughts that would be difficult without the tool. They are cognitive reflection and amplification tools that help learners to construct their own realities using the constructs and processes in the environment on a new content domain.

4 Cognitivism or Objectivism is not the Question

We have argued that cognitive tools are constructivistic, that they are designed to assist learners in acquiring, restructuring and tuning knowledge. But when and where are cognitive tools useful? Should they be used to facilitate all types of learning? Should all learning be personally constructed, or should some remain externally referenced?

It is not reasonable to assume that all knowledge should be personally constructed. Socially constructed reality will always maintain an important role in society. It is the conceptual glue that holds societies together. If learners construct knowledge based upon faulty models, then the educational system has done them a disservice. Also, much knowledge is and should remain negotiated or socially constructed. Much of our collective knowledge is extrinsic, shared knowledge. Despite individual construction of knowledge, most of us develop the same or similar schemas for much of our knowledge. We all share a general conception of "chair" because our constructions of a "hair are common enough. If we didn't share these schema, that is, we did not share similar conceptions for many or most objects, then communication would be impossible. Completely idiosyncratic knowledge constructions would result in intellectual chaos. The societal good is also served by common, extrinsically driven schema construction. For instance, pilots and air traffic controllers should not be allowed to construct their own conceptions of flying in crowded air space. Knowledge should, to some degree, be personally constructed, but it also must be societally shared. To the degree that we can safely and successfully allow learners to construct their own knowledge, cognitive tools should be used to assist them in this endeavour.

5 Summary

Learning systems in the past two decades have become increasingly cognitively oriented, investing more intellectual responsibility and intentionality in learners. Designers of learning environments and instructional systems are engaging learners in more meaningful mental processing. The next logical step in this revolution is to invest additional responsibility in the learner for personally constructing knowledge where appropriate. If we do, learners should become more self-reliant thinkers better able to relate new information to existing knowledge and better able to apply that new knowledge in novel situations. Effective cognitive tools are those that support cognitive processes, those that enable learners to engage in higher order thinking, that help learners engage in cognitive processes that would normally be impossible, or that allow learners to generate and test hypotheses in meaningful problem-solving situations (Lajoie, 1990). Learning systems and environments that employ cognitive tools that perform in these ways represent a further step in the constructivistic direction of learner empowerment.

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