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Principles of learning in multimedia educational systems

Eileen Kintsch University of Colorado
Marita Franzke U.S. West Advanced Technologies
Patricia Haley
Walter Kintsch University of Colorado

Institute of Cognitive Science
University of Colorado
Boulder, CO 80309-0344

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1. Overview

In this paper we review the literature on learning and instruction in order to provide designers of multimedia instructional systems with guidelines for optimizing learning. We try to show not only what has worked and what has not worked in the past, but to offer a theoretical framework within which these results can be interpreted and which can serve as a guide for future work. How people learn provides a set of constraints for the design of any instructional system that is at least as important as other considerations that play a role in the design of multimedia instructional systems. Our goal is to offer a guide to the practitioner as to the nature of these constraints. This requires that the practitioner become at least somewhat familiar with learning theory and the psychology of higher-order cognitive processes. With this goal in mind, we discuss and selectively review the relevant literature. Thus, this paper is not a comprehensive treatise on learning and instruction, but rather is oriented towards the needs of systems designers who must deal with instructional issues.

We take learning to be the formation and modification of mental representations. In particular, we are concerned here with abstract, symbolic mental representations that play a role in much school learning and many job training programs in industry. The medium of learning may be classroom instruction, a text of some kind, or a multimedia system combining the written and spoken words with graphs and pictures, still or video. The presentation in both texts and multimedia systems is typically linear, as in a movie or book. However, modern computer systems also permit nonlinear, learner controlled presentation sequences, as in hypertext (nonlinear text) or hypermedia (nonlinear multimedia systems). The principles of learning which we propose and discuss in this article are quite general and are not restricted to multimedia systems. However, we make an effort to point out their special relevance and role in design of multimedia instructional systems.

1.1 Forms of Learning

Even the simplest organisms are capable of learning. Needless to say, they do not learn the same way as people do. People are complicated, however. They can learn in the simplistic manner of paramecia, but they also can learn in many other ways, like chickens, like chimps, and most importantly, in ways peculiarly human. Thus, any principles of learning must be prepared in multiple editions: how people learn by habituation, by repetition and reinforcement, or by active construction of meaning. All of these are perfectly good topics for the psychologist studying learning, but these different forms of learning must be differentiated for instructional purposes. Each requires a different set of learning principles.

The lower forms of learning that people share with other animals - habit formation through conditioning, motor learning through practice, incidental learning through experience, apprenticeship through expert guidance - really need not concern us very much, for people are very good at it. If the instructor sets up opportunities for learning, provides appropriate feedback, and most of all, makes sure that the learner remains sufficiently motivated to keep at the task, instruction will succeed. This does not mean that such learning is easy or simple, and that it does not play a great role in human life both inside and outside of school, nor that there are no principles of learning worth discussing that apply to such tasks. The behavior acquired can be very complex, very difficult, and a good trainer/instructor can make all the difference in the world. However, such learning is not what we are focusing on in the present report. Neither are we concerned with another type of human learning - learning from stories. Much of what people know is transmitted by stories, oral or written or visually presented. Indeed, human cultures could not exist without this way of teaching its children, for it is a primary vehicle for transmitting a culture's acquired knowledge and values. Students do learn well from stories and from films, but once again, knowing how to tell an effective story or how to make a successful film is by no means a trivial task.

Even though informal, everyday learning proceeds rather easily and naturally, and despite the fact that we know a lot today about how to improve students' learning, school learning remains difficult, effortful, and all too often is not successful. While schools teach a variety of things, the main reason for formal schooling in a culture has to do with acquiring higher forms of understanding which require abstract, symbolic thought. Symbolic thinking and reasoning processes are difficult, they do not come easily, and students need a great deal of support, guidance and encouragement in order to sustain their motivation and effort.

We begin the article with a general discussion of the nature of cognition in order to clarify our focus here on formal, symbolic thinking and learning. We then present a set of learning principles, which are justified and elaborated by means of an overview of the cognitive research literature from which they are derived. Afterwards we describe several multimedia educational systems to give some idea of how some or most of these principles have been implemented. We then describe how such systems have been evaluated from the standpoint of our list of learning principles and conclude the paper with a discussion of open questions for future research.

2. The Nature of Cognition

Anyone who tries to gain an overview of the contemporary literature on learning and instruction will find that it is an amazingly contentious and fractionated area. One would think that after 100 years of the psychological study of learning there would be some agreement about the basics, at least. On the contrary, there appears to exist a Babylonian confusion today at the level of basic approaches to learning and instruction. Once we get beyond that point and look into each particular approach by itself, things appear much more orderly. But at the level of basic outlook, confusion reigns.

Therefore, we begin this review of the literature with a general discussion about the nature of cognition, which may seem like a detour but is necessary to avoid confusion. There are many successful learning systems in use which operate on quite different principles than the ones discussed here. Our focus is on formal school learning. However, people learn - and think - in many different ways, to which the principles listed above do not apply. The brief discussion below on forms of cognition should help to clarify what these ways are, how they interact, and why we chose to focus on one particular type of learning and instruction.

One source of confusion regarding learning and instruction is the fact that earlier research on conditioning and habit formation in the behavioristic tradition has never been reconciled with the cognitive approach, which looks at learning as a process of meaning and knowledge construction. The cognitive approach has simply shifted the discourse to a new level and taken over the spotlight, but habit learning and skill instruction remains alive and well in many settings. More recently the cognitive/constructivist approach has itself been challenged by demonstrations of situated cognition and learning through direct action, revealing a number of significant phenomena that cannot be accounted for by symbolic cognitive theories. In some sense, situativity theory takes us all the way back to non-representational behaviorism, though the former's emphasis on social and cultural factors in learning adds a completely new and significant dimension. Communication between these approaches is generally poor, as attested by the special issue of Cognitive Science dedicated to the symbol-vs.-situation controversy (No. 1, 1993).

One cannot state principles of learning without resolving these confusions. Therefore we briefly discuss a framework that distinguishes different types of learning and argue that formal pedagogy must emphasize one particular form of learning and knowing - the construction of symbolic mental models. The set of learning principles presented in the following section focuses on that particular goal. In articulating this framework we hope to avoid fruitless discussions and counter examples to our proposed principles that involve different types of learning and cognition.

2.1 Mental representations

Learning consists in the formation of mental representations that allow the learner to act in the environment in novel ways. The source of the confusion alluded to above is that several different kinds of mental representations are involved in human cognition. At the simplest level, human action is directly linked to the environment. Some authors claim that such links involve no representations at all, while others prefer the term direct representation (e.g., Gallistel, 1990) to indicate that some kind of change in the neural organization must take place to allow for new links between stimuli in the environment and responses of the organism. What characterizes learning at this level is that what is being learned are responses to the environment (e.g., a bear learning what is a good spot to catch fish). Such responses may be enormously complex and based on a sophisticated analysis of the environmental situation, but they are still under direct environmental control.

Mental representations serve to weaken the link between environment and behavior by inserting a mediating level of representation. Humans have available various representational systems that break the direct dependence of action upon the environment and allow them to reflect on past experience and to anticipate the future. Gallistel calls these indirect representations, and various authors have distinguished several subtypes of indirect representations. The important point is that all these types of representations, direct and indirect, including all their subtypes, coexist in human cognition. That is, sometimes we behave and learn in one way, like any other animal, and sometimes in another way, like primitive man or the modern symbol processor that we also are. Thus, cognition is a hybrid system, combining vestigial forms of coping with the environment with higher human functions, the higher ones encapsulating the lower ones (Donald, 1991).

This distinction between direct and indirect representations is made by many authors and has a solid behavioral and neuropsychological basis. For instance, on the basis of neurological evidence Mishkin and Petri (1984) distinguish between two learning systems, a cognitive memory system and a habit system. They show that these two systems have fundamentally different learning and retention properties, use different circuits within the brain, and store different aspects of experience. Closely related dual-learning models have been proposed by Squire (1992) and Squire, Knowlton and Musen (1993), who use the terms declarative and non-declarative memory, and by Graf and Schacter (1985), who talk about implicit and explicit memory. Neisser (in press) distinguishes between direct perception/action and social perception systems on the one hand, and representational systems on the other. Thus, there are many observations across various subareas of psychology that point to the same dichotomy between processes based on direct representations and processes based upon indirect representations.

2.2 Subtypes of mental representation

In addition to this basic dichotomy, it is often useful to distinguish subtypes of cognition at each level. Subtypes of representation are not always distinguished in this literature, and when they are, different names are used, but there is a certain amount of agreement about the major classifications. Instead of discussing the literature in detail, however, we present here a classification employed by Donald (1991).

2.2.1 Direct representation

Two subtypes of non-representational cognition, or in the terminology of Gallistel (1990), direct representation, can be distinguished:

2.2.1.1 Procedural memory is tightly coupled to the environment. In the presence of certain stimuli an organism learns to make a particular response (e.g., learning how to tie a shoelace). This capacity is shared by all animals. Learning occurs by repetition of the action coupled with reinforcement.

2.2.1.2 Episodic memory. Cognition at this level is based on episodic memory representations, that is, generalized event representations of experience, which are created to guide action and anticipate changes in the environment (Nelson, in press). Event memory is accessible to recall and reflection, and unlike procedural memory, it is a form of declarative memory.[1] What is remembered and represented in memory are concrete events, and script-like

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[1] The procedural-declarative distinction in cognitive psychology is different from the distinction betweeen direct and indirect representations because it classifies event memory together with direct representational systems. There is some reason for doing so because event memories may be coded linguistically and hence become truly representational. When that happens it is not the event itself that is remembered, but the story constructed about it. That is, the event memory has become encapsulated. The assignment of event memory to non-representational systems is strictly true only for non-verbal organisms (young children, animals). It is important, however, to realize the more primitive roots of event memory. For example, in walking through an unfamiliar hotel lobby I notice a telephone booth and say to myself "Good to know, I might need that tomorrow", as well as a coke machine which I pass by without awareness. Later I can remember both the telephone booth (intentional, goal-directed learning: event memory plus linguistic code) and the coke machine (incidental, non-goal directed learning: pure event memory).

sequences of events. Out of general event memories emerges the recollection of particular experiences, involving a certain level of consciousness and self-awareness. Event memory permits the analysis and breakdown of perceptual events. It is shared with higher animals. Learning occurs through experience, and is incidental rather than being intentional and goal-directed.

Organisms that must rely on event memory because they do not possess higher forms of cognition, such as apes, use signs and have a repertoire of social skills which depends on a rich episodic memory. However, in both cases their actions are short-term and bound to the environment. Thus, cognition at this level is analytic and reflective, but still tied directly to the environment.

2.2.2 Indirect representation

Higher cognition, characteristically human, depends on mental representations to break up the direct link between environment and action. Hence, Gallistel (1990) calls such representations indirect representations. Indirect representations are mental objects, separate and distinct from the events themselves. They are used intentionally, often but not necessarily for communicative purposes. There is no limit to the number of things and events that can be represented. Furthermore, true representations are generative, in that elements can be combined and re-combined in many different ways. Most importantly, indirect representations are not entirely under the control of the environment but can be activated at any time, subject to the limitations of memory retrieval.

Most representational thought involves language. Indeed, there are two distinct ways of thinking with language: the oral-narrative mode of thought, and formal, symbolic thought, which employs linguistic as well as non-linguistic (e.g., mathematical) representations. Bruner (1986) has called these the <u>narrative</u> and the <u>paradigmatic</u> forms of language use. Donald adds to these <u>mimesis</u>, as a form of true representation that is non-linguistic. We give a brief characterization of these three subtypes of representations according to Donald (1991).

2.2.2.1 <u>Concrete, non-linguistic, mimetic representations</u>. This type of learning is based on imitation, but goes beyond mere imitation in that it involves the formation of intentional representations. Mimetic representations, unlike linguistic and symbolic representations, are non-arbitrary. The representational gesture or object is somehow derived from what it represents (e.g., bowing the head in greeting to indicate submission).

Examples of mimetic representations are found particularly in social learning: a child's imitation of adult behavior serves as practice, and it is deliberate and generative in that it often involves novel re-combinations of various behavior segments. Arts, ritual, dance are based on mimesis. Trades learned via apprenticeship involve this level of representation (although there is usually a verbal component as well). Since imitation is inherently social, social context plays a crucial role.

Mimesis is a summary of episodic experience, allowing modeling of perceptual events in self initiated motor acts; its main role is in social behavior (the child's way of thinking about parenting is to play with her doll, feed it and dress it), the communication of emotion, ("body language") and the transmission of skills (weaving in pre-literate cultures is learned by watching and imitating an expert weaver).

2.2.2.2 Narrative-oral representations are verbal but not abstract. This type of information processing is linear, analytic, and rule governed. It yields semantic memory, propositional memory, discourse comprehension, analytic thought, induction, and verification.

Much of what we know and what we learn is in the form of stories, for example, our cultural and historical knowledge. Stories are narrative mental models: story understanding is a form of learning about the world. We understand the world when we are able to tell a coherent story about it. For example, this is how a jury comes to a decision. There is again a social component to narrative learning: stories are told by someone to someone (including one's self). Socially elaborated and sanctioned stories - myths - are the cognitive structures that hold a culture together.

2.2.2.3 Symbolic representations are required for abstract categories, logical thought, formal argument, deduction, quantification, and formal measurement. Symbols are dependent on visuographic invention: maps, calendars, clocks, artistic graphing, scientific graphing.

Symbols also depend upon external memory storage and written language. The major locus of knowledge storage is out there, not within the bounds of biological memory. Biological memory carries around the code, specifics are to be found in external symbolic storage systems (ESSS).

Pedagogy has always been directed at this level. This is where learning problems arise and where most special instructional efforts are needed. This is what school learning is largely about, and this is the level at which our learning principles are focused. However, in applying these principles it is necessary to remember what form of learning they are concerned with. Not all tasks require learning at the symbolic level; for some a purely procedural or narrative representation may suffice.

2.3 The problem of encapsulation

The neat classification presented here is greatly complicated by the fact that in the adult human lower forms of cognition are encapsulated by the higher forms. Thus, the types of cognition discussed above may be found in pure form in the phylogenetic development of man (Donald, 1991), or the ontogenetic development of cognition (Nelson, in press), but not in the adult human mind. We have already mentioned some consequences of this encapsulation for event memory: although we possess incidental memory for events, like a dog might have, we also possess explicit, language coded event memory that is uniquely human. Even procedural memory may be language coded, though not very well, as is testified by the inefficiency of verbally describing a tennis stroke or a skiing turn. Mimetic representations, too, are coded with language. Modern apprenticeships are not purely mimetic, but supplemented by oral language and even symbolic thought, as, for example a graduate student learns skills by working in some laboratory.

Modern man is largely a creature of his own fabrication. The evolution of human thought over several million years was governed by biological factors. But a few thousand years ago the basis for further development shifted from the biological realm to the cultural. This was brought about by the invention of written language and the consequent elaboration of external symbolic storage systems (ESSSs), including books, libraries and records of all kinds. As more and more powerful technologies for the external representation of human thought were invented, our current "theoretic culture" developed, characterized by abstract, symbolic ways of thinking which were out of the reach of earlier, oral cultures. Such, anyway, is the fascinating argument of Donald (1991). If there is even a kernel of truth in this account, the current technological change that ESSSs are undergoing offer bewildering possibilities. Computer-based, multimedia representation systems will forge the future human in ways we cannot even anticipate. But we can have a hand in bringing about this potential next step in our evolution. ESSSs are about to be changed fundamentally - if Donald is right, with enormous consequences.

3. Principles of Learning

As mentioned before, the principles of learning listed in this section are directed at the formal, symbolic type of learning that is the focus of academic training in school. It is important to note this restriction, for on very many occasions an instructional program will be directed at a different type of learning, to which our discussion of learning principles and the use of multimedia for their realization does not apply. Confusion and misunderstandings result if these distinctions are not observed. The type of learning that is the focus of this review is based on the following general assumptions.

3.1 General assumptions about symbolic learning

(1) Learning that involves abstract thought is best characterized as the active, intentional construction of meaning from information and experience. Learners are goal-directed and self-regulating, and can assume personal responsibility for their own learning.

(2) The result of learning is a mental knowledge representation. This representation is symbolic and abstract and needs to be well organized. It is not just a story about something. It may take many different forms, e.g., visual, verbal, or something more abstract.

(3) For this mental representation to be effective in controlling action and problem solving, it must be well integrated with the learner's prior knowledge.

(4) To construct such mental representations, the learner needs to use a broad repertoire of thinking and reasoning strategies, including higher-order strategies for selecting and monitoring mental operations. Different learners and different learning tasks may require specialized strategies.

(5) Learning is not an isolated individual activity but occurs in a social and cultural context. Technology is part of that environmental context. Learning is influenced by interpersonal relations and communication with others.

(6) Intentional learning requires a motivated individual. Emotions, beliefs, interests and habits all influence motivation.

(7) Setting appropriate standards for assessing and monitoring a student's progress towards these goals are necessary components of instruction.

3.2 Principles for designing educational systems to enhance active, symbolic learning

Although a comprehensive theory of learning has yet to emerge from two decades of research in cognitive psychology, various researchers have recently taken steps in that direction by proposing lists of principles for "active learning". This term refers to the process of actively constructing meaning from a learning situation, whether information is presented in the form of written text, a movie, video, or live demonstration, or in various forms of symbolic representations. As might be expected, the lists of learning principles overlap considerably, as does the one offered below, which draws from the work of our predecessors and their colleagues, especially: Ann Brown and Joseph Campione, (1994); Robert Glaser (Glaser & Bassok, 1989), Lauren Resnick (1989); and Marlene Scardamalia and Carl Bereiter (Scardamalia, Bereiter, McLean, Swallow, & Woodruff, 1989).

3.2.1 The overall goal of instruction is to promote the acquisition of usable knowledge, that is, knowledge that can be easily accessed and applied in novel situations. Hence, comprehension and learning processes should be directed towards building accurate and detailed mental models in a domain.

3.2.2 Instruction should be learner centered, that is, the intelligence of the learner should be exploited and engaged during all phases of instruction. Learners should be given reponsibility for:

- setting goals (e.g., choosing particular topics and subtopics for study, decomposing complex problems, planning, determining and assigning tasks, etc.);
- constructing meaning for themselves;
- monitoring understanding and progress;
- repairing breakdowns and errors;
- to a limited extent, learners may also be involved in designing, choosing and implementing assessment measures (cf. Brown & Campione, 1994).

3.2.3 Make the students' prior knowledge the starting point for instruction: encourage them to examine, use, and elaborate their prior knowledge.

3.2.4 Provide meaningful learning goals, activities whose value is evident to the learner and which are at an appropriate, moderate level of difficulty. The focus should be on cognitive goals and processes rather than on specific products (e.g., reading to understand some topic is too vague a goal; reading in order to report information back to a learning group is better.)

3.2.5 Learning should be situated in a realistic and meaningful context.

3.2.6 Create opportunities for social construction of knowledge, but provide appropriate means of sustaining dialogue, for organizing the communal knowledge base, and for managing group discussions and team activities, and for sharing responsibility.

3.2.7 Emphasize deep understanding, promote strategies for reflecting on and building new knowledge rather than rote learning.
Provide activities, such as generating questions and theories (Brown & Campione, 1994; Scardamalia et al., 1989) which provoke and sustain interest about important ideas or principles.

3.2.8 Help students develop an awareness of their own thinking processes, by allowing them to debug their own errors and misconceptions, and by bringing hidden cognitive processes out into the open, so that they become explicit objects of discussion and reflection.

3.2.9 Provide support for higher level thinking and reflection, which can be faded out as learners develop competence. Two examples (described in Section 4 in more detail) of very different kinds of support are:

- the explicit teaching of comprehension strategies using, for example, the reciprocal method of modeling, shaping and coaching students towards independent use of the strategies; (Palincsar & Brown, 1984); and
- providing explicit representation aids (e.g., pictures, graphs, tables, simulations, on-line manipulables, etc.) that help learners to construct appropriate and rich conceptual representations and to organize their thinking (Scardamalia et al., 1989).

3.2.10 Encourage flexibility in strategy use and provide opportunities to consider ideas from multiple perspectives, to apply knowledge broadly in other contexts and to seek analogies in other subject matter domains. Allow/require iterative processing, multiple passes through the material, chances to revise and reconsider one's ideas, to critically evaluate those of others (Scardamalia et al., 1989).

3.2.11 Provide rich, explanatory feedback which is relevant to the mental processing of the learner (Scardamalia et al., 1989), and at times and frequencies which will optimize learning (Druckman & Bjork, 1995).

3.2.12 Exploit errors as opportunities to advance learning. Educational software should help learners identify and remedy their own knowledge gaps and errors (Scardamalia et al., 1989).

3.2.13 Acknowledge and exploit individual differences in interest, knowledge, and abilities. Rather than expecting similar kinds and levels of performance from everyone, encourage learning within "multiple zones of proximal development" (Brown & Campione, 1994, p. 266).

3.2.14 Provide meaningful assessment measures, which are sensitive to conceptual change, which can capture how knowledge is represented across time, and which provide opportunities to further learning.

4. Justification of Learning Principles

This section presents an overview of ideas and techniques which have emerged from the last 20 years of research on cognition. This research has served as the basis for the sets of principles of learning offered above as well as in other sources and provide the rationale for recommended changes in classroom design and instruction which are currently being explored in several experimental school programs. After summarizing the cognitive research on learning from the standpoint of active meaning construction we briefly discuss how changes in our views about the nature of comprehension and learning have influenced theoretical notions about instruction.

4.1 Techniques to promote active learning derived from cognitive research

4.1.1 Expert learning strategies

The research on comprehension and learning since about 1980 has been driven by the conviction that learning is not only influenced by the design of instructional presentation and materials (how the material is broken down, explained, organized and presented with respect to the learner's level of knowledge), but also by what learners must do to comprehend and learn. The cognitive research reviewed in this section has pursued both of these directions. On the one hand, it has continued and considerably broadened the tradition of careful task analysis initiated by behaviorism, which attempted to shape and guide students' learning by appropriate structuring of the learning materials. Cognitive research has likewise pursued the goal of making the content especially of written text easier to grasp and to learn from. However, with its emphasis on learner activities, cognitive research embarked in a new direction, raising questions such as the following: What kinds of knowledge and what kinds of cognitive processes are necessary to accomplish a given task? For language based activities, what characteristics of a text contribute to successful understanding and memory? And to what extent is successful comprehension accomplished by effortful cognitive activities? What are these activities, or more precisely, what kinds of strategies characterize successful versus less successful learners and can such strategies be taught to help students learn better?

A particularly important result of cognitive research is an awareness of the degree to which reading and writing resemble problem solving, in that they involve active, strategic, effortful activities which work best when they are under the conscious, metacognitive control of the learner. (Of course, we are referring here to reading with the goal of deep comprehension, not the passive kind of reading we all engage in when, say reading the morning newspaper or to escape the discomfort of airplane travel.) Expert comprehension and learning strategies which have been singled out in reviews of this research (e.g., Palincsar & Brown, 1984; Weinstein & Mayer, 1986) include:

- elaborating instructional content verbally or with mental imagery;
- rereading, paraphrasing in one's own words to clarify the content;
- focusing attention on main ideas;
- making outlines, network diagrams (e.g., Dansereau, 1985), and elaborative notes that specify the relationships between ideas and that

involve reorganizing the ideas, for example, into a graph, a hierarchy, a different rhetorical structure or simply reordering them;

- consciously seeking relationships between new content and existing knowledge, e.g., by self explaining, forming analogies, hypotheses, drawing conclusions, predictions, evaluating text for consistency both internally and with respect to one's own knowledge, formulating questions;
- consciously monitoring on-going comprehension, for example, by summarizing main ideas, self questioning, using adjunct questions provided in the text to guide reading, and reviewing what was read.

What these interpretative strategies have in common is that they rely on inferential processing to expand and enrich the text content with ideas and concepts from the personal knowledge base. This is what we refer to as the active processes of meaning construction. And these are the kinds of strategic activities that have been shown to be deficient in poorly achieving students and learners of any age. A major goal of cognitive research has been to apply these insights to make students' learning more efficient and successful and thereby more motivating. Initial attempts thus focused primarily on direct training of the expert strategies which had been identified, especially reading comprehension and metacognitive control strategies, but also general problem solving strategies. Some of the techniques used to manipulate the learner's processing activities are outlined immediately below. It should be noted that our review focuses primarily on research in the area of reading comprehension for two reasons: First, there are more training studies and a greater variety of techniques developed for this area. But more importantly, there is general agreement among cognitive researchers about what good reading strategies are like. In contrast to reading comprehension, the identification of general and teachable problem solving strategies, which transfer broadly to novel domains, remains an elusive goal: increasingly, researchers have come to realize that such strategies must be acquired together with other skills and knowledge in a particular domain (see, for example, Larkin, 1989). Following the section on direct strategy instruction, we discuss other methods which have been used to improve students' learning, specifically manipulations of instructional materials and of the learning situation.

4.1.2 Manipulating the learner's activities through direct instruction of strategies

The direct instruction approach can be described in terms of three, somewhat overlapping categories of strategies which are directed at different levels of processing and memory representation. <u>Textbase strategies</u> are intended to improve students' ability to recall textual content as completely and accurately as possible. <u>Metacognitive strategies</u> are directed towards increasing students' awareness of their own cognitive processes and their ability to control them as needed. Strategies at the <u>situation model level</u>

involve more interpretation of textual content and more difficult kinds of inferencing, by which readers form relationships between a text and their own prior knowledge. This kind of memory representation is necessary to support later applications of newly acquired knowledge and thus constitutes what we consider to be true learning. Of course, these strategy types do not form discrete categories, but differ in relative degree of focus on a particular level or aspect of cognition. All three contribute in important ways to effective learning. Our ordering of the strategies to some extent reflects differences in the amount of cognitive complexity of the strategies, but it also reflects the chronological order in which these strategies received attention among cognitive and educational researchers. Thus, both instructional techniques and the methods used to assess their efficacy focused initially on textbase processing and employed tests of comprehension and memory, such as recall, summarization, short-answer questions and recognition of textual materials. Only recently has the emphasis shifted to learning in the sense of whether conceptual understanding is demonstrated in novel applications, such as inference questions.

4.1.2.1 Textbase strategies. Several landmark studies (Brown & Day, 1983; Brown, Day & Jones, 1983; Scardamalia & Bereiter, 1987) have documented the prevalence of low-level, surface oriented strategies among students engaged in various text processing tasks, most notably in summarizing text and in composing their own essays. Thus, school age students typically resort to a "copy-delete" approach to summarizing, rather than constructing generalizations; similarly in writing essays, they simply tell what they know about a topic with little effort devoted to planning, meaning transformation, or revision. Hence, a number of training studies attempt to teach higher-level summarization rules, such as focusing on important information and constructing macropropositions, or topic sentences. Study skills programs have been developed which teach students explicit strategies, such as:

- previewing instructional materials;
- focusing on headings and adjunct questions to guide reading;
- rereading for specific information;
- attending to important information;
- identifying top-level structures;
- outlining; and
- rehearsing and self-questioning to test readiness for a test

An approach developed by Dansereau (1978; 1985) instructs students how to do text mapping, or "networking" - forming hierarchical outlines or diagrams which show the relationships between ideas - as a way to increase students' engagement with the information presented in texts and thereby improve recall. Reviews of the literature on studies skills instruction are provided by Garner (1988); Weinstein and Mayer, (1986).

4.1.2.2 Metacognitive strategies. Metacognition refers to the ability to stand back and oversee one's own thinking processes, for example, to be aware of what one is doing in order to comprehend difficult material, to detect failures to comprehend and to take appropriate remedial action. The degree to which metacognitive awareness is involved in effective comprehension and learning is a major insight of cognitive research in the 1980's (see Brown, Bransford, Ferrara, & Campione, 1983, for a detailed review). A particularly effective method for making students' more aware of their own mental activities involves having them think aloud, not only during reading, but also as they write or solve mathematical or various other kinds of problems. It has been widely used as a technique for identifying expert versus novice strategies in a wide variety of tasks (see Bereiter and Scardamalia, 1987, for reading and writing).

Modeling of expert strategies by a teacher serves to bring hidden cognitive processes into the open so they can be observed, practiced by students, and improved under her guidance. This technique serves as the basis of a particularly successful instructional program, termed "reciprocal teaching" (Palincsar & Brown, 1984). Reciprocal teaching focuses on four general comprehension strategies - questioning unclear content, summarizing section by section, clarifying comprehension problems, and predicting forthcoming information. These strategies help students become more involved in the meaning during reading and better able to monitor their comprehension processes. Students' attempts to imitate the modeled strategies are shaped by the teacher, whose role becomes less directive as students learn to use the strategies independently. The technique is most effective in small reading groups in which students alternate in the role of teacher.

There have been several attempts over the years to develop strategy training programs in mathematical problem solving. Unlike the programs in reading comprehension, it has been very difficult to show that instruction in general problem solving strategies transfers to novel domains. We mention here only Schoenfeld's (1983; 1985, as cited by Collins, Brown, & Newman, 1989) program for the instruction of heuristic problem solving and control strategies which seems a more promising approach for several reasons: (1) The strategies taught are not formal rules, but rules of thumb (such as looking for special cases, trying to see patterns to generalize from), control strategies (such as considering different solution pathways, evaluating progress), and beliefs about oneself, the world, and the domain. (2) Instruction is embedded in a supportive framework, like reciprocal teaching, that includes expert modeling of problem solving. Thus, there are many opportunities to see how an expert struggles with a difficult problem and to reflect on and discuss alternate solution paths, rather than only being given the final, correct one. (3) Work is carried out collectively in small groups. Initially students' attempts are directed at only parts of a complex problem under strong guidance by the teacher, with this support being gradually withdrawn.

4.1.2.3 Learning strategies. We include here instructional techniques which emphasize integrative processing - the formation of multiple links being between new knowledge and concepts and ideas of existing prior knowledge. A direct approach is to teach students to generate inferences relating the content of their reading to their own experience. Although this technique was found to be generally helpful among elementary school students who are poor readers, good readers did not benefit, presumably because they generated such inferences on their own (e.g., Hansen & Pearson, 1983).

Nevertheless, active engagement in meaning construction happens all too rarely when students are reading about an unfamiliar topic. To get students to go beyond a typically passive, superficial processing mode, Chi taught 8th-grade students to explain to themselves the meaning of each sentence as they read (Chi, de Leeuw, Chiu, & LaVancher, 1994). Her study showed that students who generated self explanations developed a more accurate mental representation of a biology text and were better able to use their knowledge to answer difficult inference questions than students who simply read the text twice. Taking these findings a step further, Coleman (1994) has shown that students who are instructed to read in order to teach the material to another student learned more effectively (in terms of performance on a difficult inference task) than students who summarized or explained it to themselves. Further, explaining the text appears to be more beneficial than merely summarizing it either for oneself or for another person. Presumably explaining and teaching elicit deeper, inferential processing at the level of the situation model, by which a fully elaborated meaning representation is constructed, unlike summarizing, for which only a coherent representation of the text content (textbase) is required.

In traditional classrooms teachers often ask questions of their students as a means of organizing lessons and in order to get students involved in their reading. Usually these are factual questions which direct students to retrieve specific information from the text. By changing the nature of the questions to ones that require students to focus on the meaning and interpretation of a text, Beck and her colleagues (e.g., Beck, McKeown Worthy, Sandora, & Kucan, in press) have devised a powerful tool for getting students to reason and think about what they are reading. Instead of reproducing verbatim text information, in "Questioning the Author" students are asked to think about the author's intended meaning, to evaluate how it was conveyed and whether the author did so successfully (e.g., "What is the author trying to say there?" "Is that said clearly?"). Students are challenged to build on the ideas in the text and to relate them to their own knowledge by such questions as "Why is the author telling us that?" and "How does that connect?" Beck et al. report impressive changes in the nature of classroom discourse from teacher dominance to student initiated interactions, characterized by spontaneous commenting on the meaning and interpretation of the text, as well as challenges to others' ideas. This deceptively simple technique thus results in profound changes in the respective roles of students and teachers as students become not only more engaged in the meaning of what they read, but also more critical of the ideas expressed in their texts.

Such concrete experiences in successful comprehension ultimately make learning new and difficult content more rewarding and more effective than learning abstract strategies, whose value is much harder to appreciate.

4.1.2.4 Critique of direct instruction of strategies. The strategy training approach is primarily concerned with developing understanding in the mind of the learner, that is, with the kinds of mental representations constructed by the individual learner's and how closely they succeed or fail to approximate expert models. This kind of knowledge should play a role in the design of multimedia instructional systems, for one should be aware of what kinds of strategic behavior is a particular program intends to elicit or not to elicit. In many training programs direct instruction of strategies has had limited success, most notably among lower achieving students. According to Palincsar and Brown (1984), transfer from training is more successful when students are forced to be active, understand why the activity is useful, and know when it is to be applied. This is the case with methods such as reciprocal teaching which relies on expert modeling of expert strategies, providing opportunities for students to see and analyze the usefulness of particular strategies. Instructional programs such as Questioning the Author (Beck et al, in press), do not emphasize strategy learning (though how a teacher responds to students' comments is also a form of modeling), but rather concentrate on actively and collectively constructing a meaning representation from a text, with similarly beneficial effects on learning. An import insight from these educational applications of cognitive research is the degree to which deep understanding is the result of real cognitive effort on the part of the learner.

Despite the importance of knowing how to consciously control one's processing in a strategic manner, from the constructivist perspective (see Section 4.2.2) the explicit instruction approach tends to focus too much on traditional school leaning, emphasizing the ability to reproduce knowledge transmitted via text and lecture. Furthermore, strategy training (except in reciprocal teaching) tends to be directed primarily by the teacher, rather than encouraging self-direction. According to the proponents of social constructivism, discussed in Section 4.2.3, the latter goal can only be fulfilled by radical changes in the culture of the classroom. Restructuring is necessary in order to provide a context in which learners assume responsibility for setting and meeting their own goals (cf. for example, CTGV, 1994) and in which students and teachers become a community of learners (Brown & Campione, 1994). This approach is discussed in detail in Section 5 where various promising examples of multimedia based instructional programs are described. (See also a review by Software Publishers Association, 1995, of 133 studies of the use of educational technology in classrooms, which draws similar conclusions.) Before turning to the topic of the instructional environment, however, we must first consider several other methods which increase learners' active participation in learning and which support their efforts to develop accurate mental representations.

4.1.3 Manipulating the learning materials

Much of the earlier research on text comprehension has explored various factors which enhance or impede the readability of text. This work has resulted in widespread attempts to improve instructional texts, for example, by using headings, subheadings and various kinds of advance organizers to cue readers to the underlying structure of the text, by means of adjunct questions to prime readers' background knowledge and alert them topics to be discussed, and by trying to make textbooks generally easier to comprehend, by highlighting and defining unfamiliar terms, using easier vocabulary and sentence structures, and so on. More recently, several researchers have singled out textual coherence as a crucial factor in students' success in acquiring new domain knowledge from written text.

4.1.3.1 <u>Improving the coherence of instructional text.</u> Coherence refers to how explicitly the relationships between ideas in a text are explained. Since no text is fully coherent, readers must do a certain amount of inferencing to fill in connections that are missing. These range from rather obvious links between pronouns and their referents, or between synonymous terms, to inferring sentence connectives (e.g., because, therefore, however, etc.), to relationships between larger segments of texts (e.g., that paragraphs B, C, & D are all examples of A). To the degree that a reader has the requisite background knowledge, such inferences are easily and automatically made. However, less knowledgeable readers are greatly helped by a text which fills in the gaps in the coherence structure of an instructional text, according to studies by Britton and Gulgoz (1991) and by Beck (Beck, McKeown, Sinatra, & Loxterman, 1991). Reading a supportive text makes it easier for the reader to form a coherent representation of its content, and to remember it later. However, not all learners are helped by fully coherent texts: Even though memory for the textual content is supported by an explicit text, learners who possess adequate background knowledge may actually acquire deeper understanding of the subject matter from reading a less coherent text. According to a study by McNamara, Kintsch, Songer, and Kintsch, in press), this is because generating these inferences on their own requires more integrative processing and thus supports the construction of a more elaborated situation model. The implications of this study are discussed in greater length in Section 4.1.4.3 below.

4.1.3.2 Adding elaborative inferences and analogies. Under certain conditions these kinds of text adjuncts can help readers to form a more complete and accurate mental model of what is being described in a text, thereby making the material more memorable and easier to transfer to a novel task or situation. For example, providing familiar examples, concrete models and analogies, elaborations which single out a main point or underline the significance of a relationship between seemingly arbitrary concepts help readers by enriching their conceptualization, making it more concrete, more imaginable, and thus easier to integrate new information with what is already known. Analogies promote more active processing by forcing readers to make comparisons across different situations, and in some cases aid the restructuring of knowledge to fit new information into an existing knowledge structure (RobertJan Simons, 1982). However, such elaborative devices are only useful if they increase the meaningfulness of the text description (Mayer, 1980), whereas they may be problematic if they are superfluous and distracting, or if they distort or oversimplify what they are intended to elucidate (Simons, 1982). Also the elaboration must intersect in some way with a reader's level of knowledge. The most potent elaborations are those that readers generate for themselves (Bransford, Stein, Vye, Franks, Auble, Mezynski, & Perfetto, 1982) - if successful! - because the associations are more closely tied to the reader's existing knowledge and because the reader must invest more cognitive effort and deal with meaning at a deeper level in order to make such inferences.

4.1.3.3 Pictures and imagery. Multimedia learning systems have at their disposal a large variety of pictorial displays with which to enrich a learner's mental representation. However, our search of the literature on multimedia education has failed to uncover a systematic study of which ones are best suited for what kinds of tasks. The most useful research results we have found concern the relation between pictures and text. Because of its central importance to design issues we discuss this topic in some depth.

First of all, we should note that the presumed facilitative role of pictures is not true for all situations. For children learning to read, illustrations accompanying the text may actually be harmful, according to an early study by Samuels, (1970). In contrast, for children who are reading to learn, illustrations do facilitate learning by .8 standard deviations, according to a meta-analysis by Levin, Anglin, & Carney (1987). According to Levin and Mayer (1993), there are seven reasons why illustrations facilitate learning from texts:

- Pictures can focus attention on what is important in the text;
- Pictures often efficiently summarize a text ("a picture is worth a thousand words");
- Pictures add a concrete representation to the linguistic textual representation;

- Pictures may help to organize a text by clarifying relationships between ideas;
- Pictures may suggest an interpretation that the text fails to communicate;
- Pictures may suggest analogies via similarities with familiar objects and processes;
- Pictures may serve as mnemonic devices.

Various recommendations follow from these principles as to the use of illustrations in text. For instance, purely decorative pictures (most of the illustrations in school books according to Woodward, 1993, fall into that category) are useless, or worse, distracting. Concrete, narrative passages can do without pictures, while complex explanatory science texts may profit from illustrations. The less background knowledge and skill readers have, the more useful illustrations become. The purpose of an illustration should be clear (e.g., whether it is used for facilitating understanding, organizing, or remembering text). We describe an experiment by Mayer and Gallini (1990) in some detail in order to illustrate the conditions under which illustrations may facilitate learning from text or fail to do so.

One of Mayer's texts was a description of how hydraulic brakes work (Table 1). Two illustrations were produced for this text. One was a <u>parts</u> illustration consisting of a schematic sketch showing the major parts of the braking system with verbal labels; the other was an illustration of the sequence of mechanical <u>steps</u> involved in braking together with brief verbal explanations. Four experimental conditions were used: text only, text + parts illustration, text + step illustration, and text + both illustrations. None of this made much difference for high prior-knowledge learners, who were around 40% correct on a subsequent problem solving task. Low prior-knowledge learners, on the other hand, greatly benefited from the illustrations, but only when both the parts and step illustrations were available. With both illustrations, low prior-knowledge subjects performed as well as high-knowledge subjects on the problem solving task, but when the text was not accompanied by an illustration or by only a single illustration, their correct solution performance was almost halved. Similar results were obtained for conceptual recall, but not for non-conceptual recall or for verbatim retention (which was very high in all conditions, indicating that these subjects really had tried hard to understand this somewhat complex text).

These data are of considerable interest, first because they show that properly used illustrations can significantly improve learning from text, essentially erasing the substantial differences between high- and low-knowledge readers. Even more important is the demonstration, however, that dual coding by itself is of no use. What is crucial is that a single, coherent situation model that integrates text and picture is constructed. For that purpose, both the parts and their verbal labels had to be explicitly coordinated, and the processes described in the text had to be represented in the illustration as well. Readers with high prior knowledge could image both the parts and their functioning without needing an illustration. Low prior-knowledge readers, however, needed to be shown precisely what label went with what part of the figure, and just how they function to produce the effect of braking.

Mayer and Gallini's study identifies an important constraint on the effectiveness of multimedia instruction: the result of learning should be one single, integrated situation model rather than uncorrelated, modality specific encodings; the situation model must integrate the representations derived from different media into a single conceptual structure.

Mayer (1994) summarizes a number of additional studies which show that the results reported above generalize quite broadly. He identifies four conditions that contribute significantly to the effectiveness of illustrations in learning from texts:

- The text is explanative that is, it contains a cause-and effect chain rather than a list of facts;
- The illustrations are explanatory, that is, they consist of a series of frames depicting the states of the system along with verbal labels that identify unambiguously what parts of the text refer to what parts of the illustration;
- The domain knowledge of the learners is low;
- Performance is assessed by problem solving and inference tests rather than verbatim recall measures.

If all four conditions are met (5 studies), illustrations lead to a 91% average improvement over a text-alone control condition. If Condition (2) is violated - as in the Mayer and Gallini study above - the improvement is reduced to 10% (4 studies). If Condition (3) is violated because the learners have good background knowledge to start with, the average improvement reported by Mayer is 8% (3 studies). Finally, if verbatim retention of the text or recall of details is used to assess learning, an average decrement of 10% is found for texts with illustration (5 studies).

There are no well-controlled studies using multimedia presentation that would allow similar comparisons to be made. However, most of the studies employing multimedia that we have seen seem in good agreement with Mayer's criteria (Mayer, 1994). We suggest, therefore, to generalize Mayer's conclusions as design criteria for multimedia presentations. At least as a first approximation, they will provide usable guidelines for the design of multimedia instructional systems.

4.1.3.4 <u>Other representational aids.</u> In addition to pictures, various other kinds of displays can be used to make abstract concepts visible and concrete. Multimedia computer systems can complement text explanations with a wide variety of alternative presentations, such as tables, timelines, animations, graphs, trees, dynamic displays and simulations of various kinds. Such conceptual models do enhance understanding of scientific text, especially for low achieving learners, if they are appropriately used. According to Mayer (1989), a good conceptual model should have the following characteristics:

- the model should be complete, in that it shows all the essential parts of a system and how they are related;
- the model should be concise, presenting information at the appropriate level of detail for learners;
- the model should be coherent, such that the conceptualization is intuitively obvious to the learner;
- the model should be concrete and familiar to the learner;
- the model should provide a conceptual explanation, e.g., of how a system works; and
- the model should be correct, providing an accurate model of the system, without distorting it through oversimplification;
- at the same time the model and the vocabulary and organization used should be considerate of the learner's level of expertise.

In instructional design one should also consider at what point in the acquisition of unfamiliar content a conceptual model would be useful. According to Mayer, models are most effective at the beginning stages of learning in a new domain where they aid in the building of accurate mental representations.

4.1.3.5 Prompts. Prompts are a type of support that can be used to support learners' attempts to perform higher order cognitive tasks, for example, writing, solving a mathematical or scientific problem, or a design task. Like the support of a human tutor, prompts help students to work at a higher cognitive level by decomposing a complex problem into do-able subgoals and by reducing the amount of information to keep track of. This allows students to keep their attention focused on the mentally demanding aspects of the task. A computer system can supply prompts, much like a human tutor, in response to erroneous moves of the user or only when requested by the user. In addition, the support can be phased out as the learner becomes more accomplished.

An example of the use of concrete cognitive supports is described by Scardamalia, Bereiter, and Steinbach (1984; also Bereiter & Scardamalia, 1987), who developed a set of cue cards for increasing students' reflective processing in composing opinion essays. The cards contain diagnostic statements from which students can choose to help plan and revise their compositions. For example, planning is broken down into five general categories: generating a new idea, improving an idea, elaborating on an idea, setting goals, and organizing the ideas into a cohesive whole. Each of these general goals is further decomposed into a set of concrete cue statements (e.g., "A different aspect would be...", "I'm getting off the topic so....", An example of this is....", "My main point is...."). In a training study the use of the cue cards was modeled before the class by the teacher and then by individual students. The modeling served to let students observe the hidden mental processes involved in planning, composing, and revising. The cue cards acted as concrete reminders of these mental operations, enabling students to maintain control over multiple aspects of the writing task. The training and supports resulted in more reflective essays among 6th-grade students. There was evidence of much more thoughtful engagement in their writing: for example, in planning and dealing with problems related to goals and plans, idea level analysis of their thinking and revisions. In addition, students appeared to gain a new perspective on the role played by reflective processes during writing.

4.1.3.6 Critique of multimedia supports for explanatory text. Instructional media differ along many dimensions, such as:

- temporal aspects (permanent vs. transitory),
- granularity (continuous vs. discrete),
- sensory mode (visual, auditory),
- detectability (a beep is more detectable than an icon, for instance),
- how difficult they are to understand (usually, a picture is easier than a sketch),
- how much possibility for interaction they afford (none for an icon, considerable for spoken language),
- the complexity of their internal semantics (some are highly structured and restrictive - e.g., beep, icon, map, sketch, table, graph - while others are complex and flexible - e.g., picture, form, spoken and written language, animation, video).

Thus, in principle, depending on the type of information to be conveyed and the way it is to be used, an instructional medium can be selected that is most suitable for the purposes at hand.

Multimedia are used because alternative presentations may be best suited for different aspects of an instructional program. Various components of an instructional program have different rhetorical functions, corresponding to different speech acts: They may motivate the learner, justify an argument, provide evidence for a claim, and so on. These different rhetorical functions may be best served by different media. In our literature review, we did not come across a formal or systematic treatment of these matters for instructional multimedia. Authors clearly have some intuitive notions about the use of multimedia, but these are not made explicit. For instance, video is often used for background and introduction; music is used for emotional tone, tables for providing precise numerical information, and so on. But a systematic treatise on the rhetorical functions of different instructional media remains to be written.

In general, adjuncts, such as pictures or representation aids, and supports, such as extra coherence and elaborations appear to benefit primarily lower achieving students. Often such techniques are sufficient to boost their performance to that of higher achievers. The latter, in contrast, appear to apply more cognitive resources to the task of constructing a mental model as they read, write or problem solve, and so have less need for representational aids and supports. However, the issue of when such supports are needed and by whom is a very complex issue: Even students with good learning strategies cannot generate appropriate inferences in a domain where they have little background knowledge. Further, a trade-off situation appears to exist between domain knowledge and learning strategies, such that one can compensate for the other to some degree. Thus, decisions on when to provide cognitive supports should be based on a careful task analysis of the knowledge domain, of the task to be performed and the knowledge level of individual students: It is important to determine in each case where learners tend to get stuck and need conceptualization aids and what kind of aids would be most helpful.

A related concern is when in the course of learning and even whether such aids should be faded out. Research so far has failed to provide any specific guidelines on this problem, though Brown and Campione's (1994) notion of dynamic assessment using a sequence of graduated hints may provide a good starting point.

4.1.4 Manipulating the design of instruction

Here we describe more general decisions which must be made regarding the delivery of instruction, excluding, however, the structuring of instructional content where decisions are fairly specific to particular content areas.

4.1.4.1 <u>The role of feedback</u>. A review of instructional feedback provided by Bangert-Downs, Kulik, Kulick, and Morgan (1991, p. 215) classifies various types of feedback as follows:

- Intentional feedback can be delivered directly by the teacher to a student, or mediated in some way, for example, by answers in a textbook or via a computer.
- Feedback can be directed towards different goals, for example, it can serve to motivate students, to cue self-monitoring of their own processing, or to indicate right or wrong answers.
- The content of feedback differs in terms of the amount of information provided and how closely it follows the originally presented information in form and content.

- Finally, feedback may serve to correct errors, to present prototypic responses, to display the consequences of a response, or to explain the appropriateness of a response.

The study by Banglert-Downs et al. (1991) is a meta-analysis of 250 studies of feedback in 4 different instructional presentations: classroom instruction, text with adjunct questions, programmed instruction, and computer-assisted instruction. Results showed a broad range of effects, including some negative ones! Four variables in particular were related to feedback effects:

(1) If students could access correct answers before generating their own answers (as in programmed instruction), feedback had very small, even negative effects, since some students passively copy correct answers.

(2) Simply informing students that their responses are right or wrong resulted in lower effects than more elaborate feedback. These two variables accounted for all negative effects.

(3) The use of pretests significantly reduces the size of the positive effect, presumably because pretests serve as advance organizers and alert both feedback and no feedback groups equally to incoming information.

(4) The type of instruction in which feedback occurred also interacted with the size of the effect: feedback was less effective in programmed instruction and computer-assisted instruction than in text comprehension and conventional text-and question format. The reason probably has to do with the more complex materials used in the latter situations. In general, the size of the feedback effect increases with more complex content and when students have fewer cues or supports. Further, feedback is most effective when it causes the learner to engage in "mindful" activities, such as reorganizing to correct misconceptions. No relation was found in this analysis between the amount of feedback and the size of the effect, probably due to the emphasis on fact learning in most of the studies analyzed. The authors suggest that elaborate feedback is more critical when a student is building a complex representation, and for conceptualizations requiring inferences and knowledge use.

Other feedback considerations concern its delivery, for example, whether extrinsic or intrinsic feedback is provided, whether it occurs concurrently with a problem solving task or after its completion, whether feedback is immediate or delayed, and provided separately for each response by the student or cumulatively (Druckman & Bjork, 1994, pp. 50-51). For both motor learning (Schmidt, 1988) and skill learning (e.g., the LISP tutor of Anderson Conrad, & Corbett, 1989), immediate feedback benefits immediate performance but not long-term performance. Summary feedback (after 15 trials) is more beneficial over the long term in Schmidt's study. However, Anderson found no long-term benefits: differences in delivery of feedback did not differentially affect accuracy over time. The latter result could be explained by the fact that learners become too dependent on feedback that is delivered while doing the task and do not debug their own errors. The general conclusion, according to Druckman & Bjork, is that: "it is not optimal to deprive the learner of any knowledge of results; rather, feedback should not provide too much information too soon" (p. 51). Thing are different, however, in concept learning tasks where associations to be learned are arbitrary (e.g., learning foreign vocabulary, or unfamiliar terms and definitions). In this case, performance depends very much on immediate feedback.

An interesting example of a computer learning environment (the architectural design environment, JANUS, Fischer, McCall, & Morch,1989), which provides explanatory feedback on-line, is described in Section 5.2.2.

4.1.4.2 <u>Increasing the difficulty of acquiring complex skills</u>. Experiments in the verbal learning area (e.g., Battig, 1975) have shown that intra-task interference and in general variability in training improves list learning and motor skills. Information transfers more flexibly due to more elaborative and variable encoding (Battig). Also contextual cues are not as essential to retrieval of the information. Similarly, variable practice with multiple analogical problems facilitates the abstraction of a general schema in problem-solving tasks. What type of variation is most effective depends on the task requirements (see Druckman & Bjork, 1994, pp. 41-44).

Although complex skills training programs have generally sought to optimize learning conditions, a recent review of this literature by Schmidt and Bjork (1992) suggests that there are advantages to a more difficult learning path, as Battig's results had suggested. Specifically, these authors show that conditions that optimize performance during training are not necessarily optimal for long-term retention of the skills or the ability to generalize it. Empirical evidence is summarized showing that:

- Random practice results in better retention than blocked practice, except if practice is minimal for both motor skills and verbal tasks (spaced vs. massed practice);
- Making the acquisition phase more difficult also improves retention (e.g., intra-task-interference, as in Battig,1975), <u>if</u> the manipulation produces other kinds of processing which are needed for retention (e.g., deeper processing);
- Frequent feedback, in motor tasks and possibly verbal tasks as well is generally assumed to optimize learning. However, in fact it appears that reducing the amount of feedback during acquisition, although it prolongs this phase, fosters better retention over time (Schooler & Anderson, 1990).

- Variable practice (e.g., different speeds or distances between tasks) is better than consistent practice in improving ability to generalize motor skills. Again, this is presumably because changes in behavior from trial to trial force the learner to engage in additional or different processing activities. Acquisition, however, is slower.

Difficult learning apparently forces subjects to engage in additional processing. These processes may consist of the need to retrieve information more frequently from memory, to evaluate one's own processing, or to form novel associations, all of which aid in the formation of a more elaborate memory representation. A further disadvantage of error-free training may be a lack of
opportunities for students to practice recovery from errors.

4.1.4.3 Making text comprehension more difficult. We see parallel results to the skill learning literature in the area of text comprehension, where the use of difficult text encourages inference generation and deeper comprehension, as the following studies demonstrate:

- In McNamara, Kintsch, Songer, and Kintsch (in press) text coherence was reduced by deleting linguistic cues to coherence (e.g., replacing nouns with pronouns, deleting descriptive elaborations serving to link familiar and unfamiliar terms, deleting sentence connectives, and decreasing argument overlap by use of synonymous terms, deleting macro signals and macropropositions). This text was lead to better performance than a fully coherent text for learners with moderate knowledge background on bridging inference questions and problem solving tasks, though not on recall. In contrast, less knowledgeable students benefitted more from fully coherent text in which relationships between ideas were clearly spelled out. Long-term retention was also better among knowledgeable readers who read a difficult, less coherent text than among those who read a fully coherent text (McNamara and Kintsch, in preparation).
- Mannes and Kintsch (1987) have shown that students who read an advance organizer outline whose structure differed from that of the text they read subsequently performed better on problem-solving questions than students who read an advance organizer with the same structure as the text. The latter group, however, recalled the information more accurately.
- E. Kintsch (1988) found that college students who read a text with a poor macrostructure wrote better summaries that included more generalizing inferences than those who summarized a well organized text. The latter summaries tended to include more verbatim text sentences. However, the opposite was the case for younger students (6th & 8th graders). As in McNamara et al. in press), an adequate level of knowledge is required to generate such inferences.
- Degraded text (for example, text with letters deleted from every word) has been used to promote awareness and use of higher-order, meaning-based

comprehension strategies during reading. This approach was effective for high learners, and if combined with direct instruction also for low learners (Rauenbusch & Bereiter, 1991). In a study by Keefe & McDaniel (in press) an increase in inferential processing resulted from reading degraded text.

- Finally, a rather different kind of evidence supporting the value of difficult processing is provided by Chall (1994) in a report documenting the dumbing down of school readers or primers. Unlike 100 years ago, books which students are exposed to today are generally too easy for the average reader. Furthermore, her research shows that students who read more challenging textbooks had higher SAT scores in 11th grade. And the largest influence came from readers used in the first few grades. This result also held for low SES children. Earlier readers in this country are different from modern ones in the following ways, according to Chall: (1) they are smaller and easier to carry around; (2) they contain fewer pictures and only in black and white; (3) instead of a teacher's guidebook, questions and new vocabulary are interspersed throughout the selection in both student and teacher texts, consequently more time was spent on reading the passage than on end-of-passage exercises; (4) the content of early readers contain more sophisticated and more difficult content.

4.1.4.4 Novel approaches to composing essays. Various techniques have been developed by Bereiter and Scardamalia (1987) to break students away from their typical, sentence-by sentence approach to writing a story or opinion essay. For many students "think-say" writing is a convenient device for completing a writing assignment, one which requires a minimum of effortful and thoughtful engagement. However, by having students complete an unfinished story, or write forward from a provided ending, students were led to spend more time in planning their essays and on problem solving as they wrote. Here, the added difficulty of satisfying specific constraints became a means of promoting more thoughtful kinds of composing activities.

4.1.4.5 Costly rather than simple computer interfaces. Recent studies of human-computer interaction lend further support to the argument that effortful processing may have beneficial effects on learning in a domain. In computer programming tasks, dealing with difficult interfaces can improve learning of a new interface by increasing the amount of planning, even though it slows the process of learning itself (Svendsen, 1991, cited in O'Hara & Payne, submitted-a) These studies suggest a way in which students can be brought to work on problems in a mindful and effortful way. Svendson's (1991) earlier experiment shows that students working on the tower of Hanoi problem, acquire the rules for this problem more efficiently if it is made difficult for them to manipulate objects in the problem domain. Subjects were either using a direct manipulation interface or an interface in which moves had to be entered via short commands. As a side effect of this manipulation, errors were easily corrected in the direct manipulation condition, but were somewhat effortful to undo in the command based interface. Performance data show that subjects solved the problems faster in the direct manipulation interface, however at the expense of a large number of errors and corrections. Subjects in this interface produced a much larger number of moves. Subjects using the command-based interface took longer to solve the problems, and they spent that time considering each move - they produced fewer mistakes and therefore fewer corrective moves. Interestingly, subjects in this condition were well able to state the rules of the tower of Hanoi problem later on, whereas the subjects in the direct manipulation task could not summarize the rules. The troublesome interactions with the command-based interface therefore forced the students to spend more effort analyzing the problem space to prevent mistakes, which in turn led to better learning of the problem domain. Naturally, the subjects did not like this activity: they rated the direct manipulation interface higher on a range of dimensions (ease of use, etc.), and greatly underestimated the number of mistakes they committed in that interface.

O'Hara and Payne followed up on this work by investigating the cost of operations in an interface more carefully. They varied the cost associated with moves in different types of problems in different ways (number of keystrokes per command, system response times and undo), and replicated the same findings in all those experiments: Higher costs associated with operations lead to longer planning times and fewer total moves to solution; rules acquired in this way also transfer better to new problems. In other words, although these subjects were spending more time preventing themselves from committing errors, they were also engaging in thoughtful and effortful analysis of the problem space which benefitted their ability to transfer the newly acquired skills.

4.1.4.6 <u>Critique</u>. What most of these techniques for increasing the difficulty of acquiring new knowledge have in common and the reason for their positive effects on learning is that they force the learner to work at a cognitively deeper and more effortful level. Forcing learners to fill in missing information from their own knowledge base, to reorganize information, to transform it, (e.g., by correcting misconceptions), or to question existing knowledge makes them work at the level of the situation model, rather than getting by with a more superficial level of understanding. However, the drawback is that only learners with some prerequisite level of knowledge will be capable of generating the right kinds of inferences in a difficult learning situation or in reading inhospitable text, as well as having the motivation to make the cognitive effort. Knowledge lacks can be greatly helped by providing supports which would make it easier for such learners to work at a higher cognitive level, that is, at the upper bounds of their "zone of proximal learning" (Kintsch, 1994, after Vygotsky, 1978). For instance, cognitive supports (see Section 4.1.3), such as Scardamalia and Bereiter's (1987) planning cues for writing or Mayer and Gallini's (1989) model of a mechanism lesson the memory load by helping learners keep track of multiple aspects of a complex task like writing, or keep their attention focused on relevant aspects of a problem they are trying to solve. Support may also be in the form of coherent text with explicit linguistic and nonlinguistic cues to the underlying structure which reduces the inferencing load for the comprehender with little background knowledge.

Cognitive research has provided educational software designers with a plethora of ingenious techniques and ideas for enhancing active learning. However, it has also brought the realization that transforming these suggestions into useful learning tools is only part of the problem. The other part is that their effectiveness depends largely on the environment in which they are used (see also the report of the Software Publishers Association, 1995). Even the greatest multimedia visualization tool will be of little help unless it is incorporated in a meaningful way into related classroom activities, discussion, and instruction. Hence, we believe that the real challenge and opportunity for successful implementation of multimedia instruction is for it to become a force in engineering change in the instructional setting. There are a few real success stories with such attempts, which will be described in a later section (Section 5). However, before turning to that topic we first provide some background about the changes that have occurred in our theoretical views about instruction.

4.2 Theoretical views on instruction

4.2.1 <u>Behaviorist model</u>. For many years formal classroom instruction in this country has been dominated by the behaviorist model of learning with its instructional focus on the acquisition of factual knowledge by learners working largely in isolation. School learning is conceived as the assimilation of a particular set of concepts and skills that characterize a subject domain. The complex knowledge in a domain is decomposed into a hierarchy of smaller, discrete elements - so-called "basic skills" - which are to be learned in a bottom-up fashion. Learners are first introduced to simpler, subordinate concepts/ideas/skills and gradually advance to more and more complex levels until mastery is attained. Thus, this traditional instructional model is one of knowledge transmission: The teacher (guided by curriculum goals set by the school district) is in charge of most of the decision making: presenting the information to be acquired by students, selecting appropriate reading, learning tasks, and assessment measures. In addition, she manages students' learning by asking questions and monitoring student's understanding and progress. Students in the traditional classroom are considered passive recipients of the transmitted knowledge who are rewarded as they successfully progress through levels of subordinate and superordinate skills.

4.2.2 <u>Constructivism</u>. Recently, under the influence of research in cognitive psychology, a more process-oriented view of learning has taken hold in educational research settings and in some, more progressive schools. This model, termed constructivism, following the Piagetian tradition, views learning as the result of active participation on the part of the learner. Rather than being a passive recipient of transmitted knowledge, learners, like young children, attempt to construct meaning from their environment. Thus, instruction should support this natural tendency to extract coherent interpretations out of information and experiences.

Whereas the traditional model of school learning has emphasized the acquisition of a body of factual knowledge, constructivist educators emphasize the conceptual processes by which understanding is achieved. Understanding here, means not only being able to reproduce information from text or lecture, but to understand the situation being described. Thus, repeated exposure to a subject matter and overt attempts to memorize play a much smaller role than in traditional schooling. Instead, constructivists emphasize more effortful processes of meaning construction: generating inferences, reorganizing, reflecting upon, and acting upon information.

In Resnick's (1989) summary of the constructivist model of learning, the following aspects of meaning construction are singled out:

- Prior knowledge is the starting point for learning. We learn most effectively by elaborating new information and reasoning about it on the basis of what we already know. In so doing new connections are formed between elements of new and prior knowledge, novel relationships are established between elements of knowledge in the knowledge base.

- It follows that the more knowledge one has, the deeper and broader the extensions of prior knowledge become. Expertise in a domain rests upon the availability in memory of a large body of well organized and interconnected pieces of knowledge, which can support a broad range of cognitive activities: drawing inferences, perceiving analogies, generalizing to new areas, and constructing deep-level, "principled" representations of new knowledge. These, rather than the parroting back of transmitted information, are indicators of true learning.

- Being able to access relevant knowledge for use in novel situations, however, also depends heavily on the context in which it was learned. Acquiring new knowledge in a meaningful context greatly enhances the ability to remember and access new information as needed. Effective use of new knowledge is further enhanced by learning settings which resemble the setting in which the skills will later be used. The argument here is against teaching isolated and decontextualized facts and skills, for example, mathematical operations, whose usefulness is not apparent to students. Such information tends to be quickly forgotten and even if remembered, one often does not perceive its relevance to novel or real-life situations.

4.2.3 Social-constructivism. Influenced by Vygotskian (1978) views concerning the important role played by social interaction in a child's development, many constructivists are placing increasing emphasis on the social context in which learning takes place. Learning, in the social-constructivist view, is a process of enculturation, of acquiring the shared practices of a (scholarly) social community. In fact, in the recent theoretical positions of some leading proponents of educational change (e.g., Scardamalia, Bereiter, & Lamon, 1994; Brown & Campione, 1994) the focus of instruction is no longer on changing the conceptual understanding of individual students. Instead, it is assumed that this will occur indirectly through an individual's participation in the joint effort for understanding undertaken in a social group. Thus, we have witnessed not only a shift in the role of the learner assumed by these educational models from passive to active participation, but also in the view of the kind of knowledge that the learner must acquire: For the behaviorist, this knowledge consists of a hierarchically organized set of skills and conceptual structures which define a particular discipline and which exist out there in the world. The constructivist focuses more on the mental activities and representations by which conceptual change takes place in the mind of an individual learner. In contrast, for the social constructivist, conceptual understanding emerges from learning the practices of collaborative inquiry and problem solving within a social group. Thus, social and cultural processes completely subsume individual cognitive activities in this view. Bereiter (1994) further specifies that the process of inquiry should focus not merely on information gathering or solving particular problems, but only as these undertakings serve the goal of "*improving the knowledge* that is being collectively created" (p. 23). Thus, inquiry, as in a scientific research community takes the form of questioning, explanation, conjecture, and theorizing, on (re)discovering underlying principles.

4.2.4 Situated cognition. The educational model that best accommodates the social-cognitive viewpoint is that of situated cognition, rather than the didactic approach favored in most classrooms. Learning is situated in a real-world-like context, in which learners form a collaborative group engaged in a complex and meaningful task. They learn important academic skills, such as mathematical concepts and operations, in a practical context by attempting to solve naturalistic problems, such as performing a complicated rescue mission (CTGV, 1992), or engaging in a research project (Brown & Campione,1994), or repairing bicycles for a city transportation program. Most models of situated learning also seek to introduce elements of traditional apprenticeship situations into these settings (e.g., Collins, Brown, & Holum, 1991; Collins, Brown, & Newman, 1989). Learners acquire new skills by observing and imitating a skilled master as he or she performs each subpart of the task; by attempting to perform the task themselves while being coached and guided by the master or by other more advanced learners; this support is gradually phased out as the learner becomes more accomplished and independent. In addition to enabling students to better perceive relationships between formal abstractions and real-world situations, this approach also stresses the importance of making explicit the thinking processes of both learner and tutor. By encouraging reflection on and articulation of hidden cognitive processes, learners gain metacognitive awareness and control over their thinking. These features have been incorporated into several instructional programs, described in Section 5 of this paper, which have as their model the collaborative inquiry that characterizes a scientific research community (Brown & Campione, 1994; Scardamalia, Bereiter, & Lamon, 1994).

4.2. 5 Learner control. Another aspect of learning which has undergone notable change in recent years concerns the matter of who controls the learning situation. Questioning the traditional notion of centralized control in the hands of the classroom teacher brings forth a gamut of possibilities which have far-reaching implications for computer assisted instruction. On the one hand, some constructivists have embraced the totally non-interventionist strategy of open exploration, which derives from ideas voiced by Dewey (e.g., 1938) and earlier by Rousseau (1979), that given a rich learning environment children are capable of discovering important truths for themselves. Papert's LOGO environments provide implementations of this viewpoint (e.g., 1980; 1993)[2]. At the other extreme we have intelligent tutoring, such as Anderson's geometry tutor (1992), in which the learner's progress is carefully guided by correcting errors and providing feedback whenever the learner strays from the path towards expert competence. In between we have a fruitful debate about the value of having learners set their own goals, monitor their own understanding, remedy breakdowns, and correct their own errors and misconceptions. Emerging from this debate are designs for classroom restructuring with these goals in mind (e.g., Scardamalia & Bereiter, 1991; Brown & Campione, 1994; Brown & Palincsar, 1989), together with computer tools to support these activities (e.g., Scardamalia et al.'s, 1989, design for computer assisted classroom learning; or Fischer' et al.'s domain tutors with built-in critics). However, critical voices are also being raised, pointing to advantages of the didactic approach under certain conditions (specifically, for learning in abstract, formal domains and when the teacher assumes a more supportive rather than strictly authoritarian role - Weinert & Helmke, 1995). Clearly, one's views about learner control have important repercussions on decisions about the role of support, feedback, and difficult learning, which were discussed in this section.

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[2]Note that neither Dewey nor Papert espouse the idea that children's exploration should be totally unguided or unstructured. Within Papert's LOGO worlds children are "empowered" through access to powerful yet easy to learn computer tools which can be used to construct complex objects or whole envirnoments on the screen according to their own wishes. In so doing, children explore and learn about mathematical, spatial, design and many other relationships in an experiential manner so that abstract concepts become more meaningful than when taught formally.

5. Case studies of successful multimedia instruction and classroom management systems

5.1. General Systems

5.1.1. Community of Learners

Authors
Brown, A. L., and Campione, J.

Reference
Brown, A. L., and Campione, J. (1994). Guided discovery in a community of learners. In K McGilly (Ed.) . Classroom lessons: Integrating cognitive theory and classroom practice. Cambridge, MA: MIT Press.
Brown A. L., & Palincsar, A. S. (1989). Guided, cooperative learning and individual knowledge acquisition. In L. B. Resnick (Ed.), Knowing, learning, and instruction: Essays in honor of Robert Glaser. Hillsdale, NJ: Erlbaum (pp. 393-451).

Age/grade range
Elementary school

Content domain
Mainly language based subjects, in particular biology. The program focuses on classroom structure and management to support collaborative learning.

Which educational or cognitive theory is it derived from?
(1) The notion of guided discovery and guided participation informs the design of an instructional setting that is midway between didactic teaching and open discovery. Active, self-directed learning is emphasized with the teacher acting as a facilitator, orchestrator.

(2) Vygotsky's notion of shared discourse forms the basis for classroom organization which seeks to promote a sense of community with shared ideas, values, and goals. This social context also provides support for individuals learning at different rates and stages, i.e., within multiple "zones of proximal development". These are defined as the region, or "bandwidth of competence" within which effective learning can take place (Brown & Reeve, 1987).

(3) Other key ideas include the notion that tasks and goals should be purposeful and situated in meaningful contexts; they should foster active, strategic learning processes and metacognitive awareness thereof, as well as individual responsibility for setting and achieving goals and for evaluating progress.

Locus of control
Topics and subtopics for exploration and study are jointly negotiated by students and the teacher.

Teacher's role
The teacher's role is complex and varied. Teachers must be able to diagnose students' current level of understanding; to facilitate learning by feeding information at the appropriate level and time; to guide the individual and group discovery process into disciplined inquiry (p. 230), i.e., to make sure that the curriculum is "discovered, understood, and transmitted efficiently" (p. 237); to model expert thinking and learning strategies;

Curriculum
The focus is on interesting questions, broad concepts, underlying themes which are revisited often at increasingly deeper levels of understanding and complexity. How these questions are approached is largely up to individual students and teachers in a classroom: both nominate subtopics and subunits for possible selection which are constrained by the underlying theme (an example from biology is "endangered species")

Curriculum is developed via:

- questions generated by students and to some extent also by teachers, which are posted on a bulletin board for general consumption;
- the questions are discussed and organized in order to select subthemes and subunits for study. For example, one class focused on mechanisms in biology, another on habitat with mechanisms folded in;
- critical ideas are singled out, major cross-cutting themes such as metabolism for further study;
- presentation by subgroups of researchers on a particular question of interest.

Didactic methods

- Reciprocal teaching (see Section 4.1.2.2) is used as a tool for organizing discussion in small group "research seminars".
-"Jigsaw" teaching seminars are used to convey results of individual and small group research to the larger group.
- Communities of learners refers to the small separate research groups in which each student becomes an expert on one subunit of the subtopic which the group is responsible for. This is termed "majoring". In this way each group and each student within a group is individually responsible for teaching their results to the group as a whole, termed "jigsaw". Knowledge is thus distributed across the entire classroom; the diversity and interest of individual students is acknowledged and exploited, as "subcultures of expertise" develop. Activity cycles back and forth between individual reading, research, self reflection on own subtopic, small group and whole class interactions.

- The main form of interaction is dialogic, initiated by questions, ideas, and comments written on Post-its and posted on bulletin board (what CSILE does via computer - see Section 5.1.2).

- The questions serve to seed ideas and to create zones of proximal development; these ideas, concepts, terms can then migrate to other participants, be appropriated into their own thinking; they become part of the common discourse; this occurs in a multidirectional manner, i.e., the student learns from an expert and the converse, and learners can access this database at their own rate and as needed and according to their current zone of proximal development.

Classroom structure
Classroom management is based on a few, recurring participant structures which clearly delineate participant roles, providing a guiding structure for individual discovery which students easily recognize:

- often the class is divided into 3 groups: 1 composing on the computer, 1 conducting research via books or various media, 1 interacting with a teacher, e.g., concerning their presentation;
- research seminars are organized around reciprocal teaching;
- teaching seminars - jigsaw, filling in your piece of the puzzle to your research group or the group to the class as a whole;
- crosstalk - informal reporting to the whole classroom on progress, or asking for clarification, explanation, information;
- benchmark lessons - are used to introduce new information or synthesize current thinking about a topic; to model thinking skills, stressing higher-order relationships between subtopics and overall topic.

Assessment of learning
An impressively rich variety of measures were developed in this training study to assess the kinds of changes in deep level, conceptual understanding which the program sought to teach and which standardized tests are largely unable to capture (cf. also Section 6.3.1.3).

(1) <u>Pre- and Posttests</u> consisting of both static and dynamic measures were used to compare a (5th-6th grade) research classroom with partial control (first semester research, second semester regular classroom), and control (regular classroom only). groups:

- short-answer quizzes on the entire theme following each unit, half of the questions were generated by student research teams, half by the staff; results showed that research team outperformed partial control and control on acquisition of domain content;
- clinical interview: a series of questions first assessing basic knowledge of a concept, followed by a thought experiment and problem-solving task that require students to apply their knowledge to a novel situation (e.g., students may be asked to consider counter-examples or what-if situations, to group key ideas into categories and then to justify their answers); when a student cannot

answer the tester uses a series of graduated hints and examples to assess the student's current level of understanding and readiness to learn a particular concept; changes in reasoning mapped across time, showed a greater tendency to reason on the basis of the principles and concepts taught (as opposed to mere facts) among the research classroom than among the control classes;

- novel application questions: for example, students were asked to design an animal for a particular habitat and the converse or to design an animal of the future; again, the research class was superior to the control classes in number of biologically appropriate mechanisms they included in their designs and in novel variations of the principles taught;

- reading passage comprehension on non biology materials were tested by various kinds of questions (4 factual, 4 inference, 1 gist, 1 analogy); the research group outperformed other groups; in particular the students in the research group showed impressive gains on inference and gist questions and in their ability to reason with analogies.

(2) On-line of conceptual change tracked the development of argumentation skills in student dialogues over time, focusing on arguments based on

- surface similarities to relying on deep analysis;
- on use of facts to causal explanations (e.g., mechanisms);
- on using explanation only if comprehension breaks down to resolving inconsistencies to spontaneous use.

(3) Portfolio evaluation - no description of scoring given.

Resources

No more than a maximum of two adults (teacher + aide) were involved with the children in a given class; the classes also depended on:

- cross-age tutoring (face-to-face and via email) in which student tutors received four weeks of training
- using students as discussion leader, also trained;
- outside guest teachers who are subject area experts;
- use of email to get specific information from outside experts.

General evaluation

(1) Strengths

- distributed expertise: shared responsibility, there are multiple ways into a subject domain, everyone becomes an expert in some area, and expertise occurs opportunistically, together with the structure provided by reciprocal teaching and jigsaw allow everyone to participate, so that the usual inequities and power problems in collaborative learning become diffused;
- exchange of leadership roles: learners become teachers and teachers learn from students.
- multiple roles and types of skills are modeled;
- everyone is at some point actor and audience; teaching reveals gaps in one's knowledge, which motivate the push for more understanding;

- sustained complex thinking, both in small groups and whole class develop together with an intolerance of sloppy thinking.

(2) Weaknesses

- an important need is to get beyond the classroom to enrich the knowledge capital of the learning community (p. 262);
- teacher competence: guided discovery places a heavy load on the teacher who has to foster discovery and also furnish guidance; the teacher also has to make on-line decisions about when to intervene, be able to correct serious misconceptions (i.e., have the correct information and know whether or not to let a misconception persist), to model expert thinking skills, to develop appropriate assessment measures;
- misconceptions may be potential problems but may also offer occasions for learning, i.e., "fruitful errors", however, this can be at least partially compensated for by making teachers aware of common misconceptions.

5.1.2 CSILE - Computer Supported Intentional Learning Environments

Authors

Scardamalia, M., Bereiter, C.

Reference

Scardamalia, M., Bereiter, C. , & Lamon, M. (1994). The CSILE project: Trying to bring the classroom into World 3. In K. McGilly (Ed.). Classroom lessons: Integrating cognitive theory and classroom practice. Cambridge, MA: MIT Press.

Scardamalia, M., & Bereiter, C. (1993). Technologies for knowledge-building discourse. Communications of the ACM. Special issue: Technology in education, 367(5), 37-40.

Scardamalia, M., Bereiter, C., McLean, R. S., Swallow, J., & Woodruff, E. (1989). Computer-supported intentional learning environments. Journal of Educational Computing Research, 5(1), 51-68.

Content domain

Mainly language based subjects across the curriculum: e.g., history, social studies, science, literature, geography, and some mathematics.

Age/grade range

elementary through middle school so far.

Which educational or cognitive theory is it derived from?

CSILE is based on constructivist and Vygotskian notions of socio-cognitive learning; the model for a school classroom is the scientific research community, as in Brown & Campione (1994). Instead of knowledge transmission/assimilation and individual achievement, the analysis and evaluation of ideas take place at the group level in a progressive dialogue.

Instructional context The computer supports a communal database for the entire class; the teacher works with students' contributions to the database any way desired. CSILE can function in a range of contexts - from traditional classrooms to a curriculum based on student initiated inquiry, as here. But the software really facilitates the latter kind of information flow and aids in restructuring the classroom focus towards Popper's "World 3 objects" (theories or beliefs, hypotheses, evaluation, etc.) and away from an emphasis on fact learning.

Where is the locus of control?
Inquiry is based on student generated notes, but guided by the teacher, i.e., teachers do not direct discourses, but participate in them, modeling expert learning.

What kind of learning does the system support?
CSILE is a tool which facilitates knowledge building as a communal activity from which individual knowledge also increases, but the focus is away from individual performance and products. However, activities go back and forth between articulation of ideas in a group and individual reflection.

How is the content structured ?
The focus is on knowledge itself, the overt representation of concepts, jointly understanding, analyzing, and evaluating important ideas (e.g., gravity, electricity) with the goal of advancing knowledge itself. The idea is that understanding is achieved by reconstructing the discovery of a theory (cf. Popper, cited in Scardamalia & Bereiter, 1993, p. 38). So knowledge building occurs through progressive discourse about ideas, theories, consequences of theories, and so on, in a community of learners. The computer database which supports and organizes this discourse thus serves as a vehicle for changing the educational processes occurring in the classroom away from knowledge assimilation and in the direction of scientific discovery. Students engage in a variety of activities at any given time, instead of all doing the same thing at a given time: e.g., video demonstrations, whole class discussion, small group problem solving, individual reading, entering notes and comments into the database, ultimately selecting text and graphics for printing and display.

What does the learner construct or manipulate?
Each student has 30 min. per day on the computer to generate any of the following:

(1) Group Notes on a particular problem, consisting of questions, hypotheses, theories, comments on others' notes, evaluations, revisions, or students may

simply browse the database. Each note is identified by author; however an author's initial note on a new topic may remain anonymous, and although anyone is free to add comments to it, only authors may delete or revise their own notes.

(2) Summary Notes which are intended for occasional updating to provide a synthesis or evaluation of group progress vs. focus on individual beliefs in Group Notes. But in actual use, students tend to merely provide a collection of undisputed factual statements.

How is prior knowledge used?
The commenting process continuously requires students to draw on their own knowledge and to seek knowledge from all kinds of outside sources (reading, interviews with experts, museums, science centers, home, CD-ROM encyclopedias, intelligent tutors, all manner of other databases, etc.)

Opportunities for transfer
The system fosters the kinds of interactions in which analogous problems are considered and multiple cross-domain comparisons are made.

Amount and type of support, when provided
Support mainly comes from peer comments and interactions, though the teacher may intervene to provide guidance or additional information when needed.

Computer supports include alternate ways of structuring or representing information, such as: timelines, graphs, maps, charts, narrative sequences, concept nets, causal chains, pictures, (self generated or accessible from other sources), zoom capability to get different levels of detail and attach notes at any level.

Specification & range of tools that are available
The computer is in a supporting role, serving to maintain and organize the progressive discourse generated in student notes. The database consists of notes and graphics. There are 8 networked computers per classroom, connected to a file server to maintain the communal database. Implemented with a client/server architecture with server written in C, with Unix (C, XWindows, TCP/IP) and object-oriented Macintosh (C++, MacApp, TCP/IP and AppleTalk) clients. Macintosh equipment is now in use in some grades, allowing all grades to be linked by a common LAN.

The tools allow users to search, browse, and retrieve files, word processing, graphics. The database consists of text and graphics. Some organizational functions are available (e.g., labeling, interrelating, sorting, reorganizing - all performed by the students), and these are a high priority need for future development (see specifications in Scardamalia & Bereiter, 1993). Video technology will also be incorporated later.

Forms and levels of interaction with tools
Students generate written communications and explanatory graphics. Graphics cards may also be used to organize notes. Anyone can add a comment (text or graphic) to a note, but only authors may revise or delete a note. Students may also build in special features, such as a spell-checker.

Errors and feedback
Error correction and feedback are provided largely by other students' comments and occasionally by the teacher as needed. An author is notified when a comment is made on his/her note.

Interest, aesthetics
Learners show high interest and high engagement in the activities

Assessment of learning
Even though just in its beginning stages, this program, as well as that of Brown & Campione (1994), is one of the few where comprehensive evaluation is taking place. A comparison study of Grades 1-6 with and without CSILE (note that the school where CSILE is implemented has combined grades):

(1) Standardized tests: While the groups were equivalent in math, CSILE outperformed control classroom on language based skills. The latter result is not surprising, since CSILE does not focus on mathematical problem solving. Standardized tests are not sensitive to intended outcomes from CSILE, but indicate no loss in achievement.
The remaining assessments are generated by the researchers:

(2) Depth of explanation:
(a) student explanations of what they had learned, scored for depth of explanation (elaborated explanation of topic vs. list of facts): CSILE classes scored higher than control.
(b) quality of graphics explanation - text followed by questions requiring diagrams and explanations: CSILE classes gave more advanced explanations containing more causal/dynamic information; no difference between groups on the descriptive score.
(c) portfolio evaluation (Grades 5/6) of own selections and of another student's: CSILE classes provided more detailed and more reflective comments, often citing learning goals.

(3) Solving analogous problems - no difference between classes in fall, but in spring testing CSILE classes performed better than control on correct solutions and recall.

(4) Students' beliefs about learning were examined by means of a 30-item forced choice questionnaire about what is most important for learning: CSILE classes displayed a deeper conception of learning (with comments such as "thinking deeply about reading", "new understanding" vs. control group who tended to say "reading the book correctly, getting good marks").

(5) Importance of computer support: comparison of small cooperative group problem solving with CSILE after watching a Jasper video of a complex problem (see Section 5.2.1 below). Small group problem solving tended to get bogged down in subproblems, while CSILE students kept better track of high level goals (data from transcripts of discussions). Better performance was also shown by CSILE students on novel, related problems. One possible reason is that there is wide variance in the amount contributed by the members of collaborative groups, whereas in the CSILE classroom all students participate equally, regardless of gender or achievement differences. Social competition does not destroy the learning.

General evaluation

This systems seems to make extensive use of learners' intelligence and prior knowledge and maximizes the amount of active processing in a classroom based program. Of all collaborative approaches, this one, together with the classroom management strategies used in Brown & Campione's (1994) Community of Learners, CSILE achieves maximum and fairly equal participation from all members of a class; differences in gender, cultural, and economic background, interests, and even ability are accommodated in a natural fashion. Social power struggles that destroy many collaborative groups are not a problem. Furthermore, this general approach could easily be adapted to training in industrial and business settings.

Assessment is well conceived and extensive. Ingenious measures have been developed for getting at depth of understanding of what learning is about, what knowledge is. Future assessment will be directed towards evaluating quality and progress of classroom discourse over time.

Future technological needs

Scardamalia & Bereiter (1993) provide a critique of available software tools which tend to perpetuate superficial school strategies - strategies which get the task done with a minimum of cognitive effort (e.g., copy-delete summarizing, knowledge telling in writing, use of superficial cues in word problems). These include software tools whose goal is to make existing information easily available to students, e.g., intelligent tutors (which make students knowledge recipients rather than knowledge builders), presentational software with cut and paste tools, file transfer from different applications, email and bulletin boards as typically used. With these applications the students' task is basically to reproduce the obtained information in some form (paper, test, report, etc.), not to rework and transform the content.

Instead, Scardamalia and Bereiter argue that "The flow of information must allow for progressive work on a problem, with ideas remaining active over extended periods of time and revisited in new and unexpected contexts" (p. 38). The model of learning in the CSILE classroom resembles scientific discovery and theorizing - working toward more complete and coherent understanding. It is a dialogue of "conjectures and refutations" in Popper's words (cited in Scardamalia & Bereiter, 1993, p. 38).
In this article Scardamalia and Bereiter outline the software features needed to support knowledge building via progressive dialogue as follows:

(a) the ability to move back and forth between public and private space, to create notes anonymously if desired and access others' ideas to advance one's own understanding;

(b) keeping ideas alive for public debate, which requires commenting, labeling, and linking facilities, notification systems which link users and ideas;

(c) source referencing so that an author's idea remains central and comments contributed by others can be reviewed;

(d) storage and retrieval indexing to increase chances that ideas will be accessed from different contexts and problem domains;

(e) organizational mechanisms to deal with information overload: ideas need to be multiply tagged, linked, referenced, subordinated, superordinated, etc.; notification is made to authors when ideas are fading from lack of attention which encourages an author to reinstate, revise, delete, so that ideas of limited value don't remain in the main database;

(f) linked resources to broad knowledge resources: home, science centers, museums, etc., to CD-Rom encyclopedias, microworlds, intelligent tutors, etc. "to expand dialogues in the central workspace and to enhance the educational value of linked resources". (p. 39)

Research questions

The classroom management systems developed by Brown & Campione and Scardamalia and Bereiter raise a number of interesting questions, especially in considering extensions of these approaches to other populations of learners in professional or other advanced training settings.

(1) Role of the teacher: how much expert intervention/guidance is needed and how does this change depending on the composition of the group? In a classroom setting unguided exploration has not been shown to work well.

Students in CSILE largely set their own curriculum of inquiry about "interesting facts" and assume the role of providing feedback to each other via commentary on notes, while the teacher models expert learning strategies. Classroom management techniques structure activities, such that different groups of students are engaged in different kinds of activities at a given time (individually composing a note, small group discussion and problem solving, whole class discussion). But at some point the teacher apparently leads open discussions and provides "benchmark lessons" (diSessa, & Minstrell, in press: Minstrell, 1989), to synthesize the understanding achieved so far. She probably intervenes to keep the dialogue from wandering too far off track, e.g., to clarify lingering misconceptions, or to suggest other data sources. However, the teacher's role is not described very fully in these papers.

(2) Learning at advanced stages raises questions concerning how much direction or structure would be needed if all members of the group have some or a great deal of expertise. If the dialogue is among members of a scientific research group, a group member may assume the role of synthesizing and organizing new understanding. In an adult training session, perhaps this role could be assigned to one of the members, or rotate among all members, such that no expert guidance is needed.

(3) Is it more productive of reflective thinking if students have unlimited time on the computer or if they are restricted to, say, 30 minutes a day, as in CSILE? Empirical research is needed on this issue,. It is quite possible that more thoughtful and better articulated ideas are entered into the communal database if there are constraints on freedom to access the database.

(4) The compatibility of CSILE' computer supported dialogic model with Brown and Campione's classroom management strategies should be noted. Indeed, these two programs, have been combined and further extended to include the Jasper macro-contexts for mathematical problem solving, described below. These three programs form the core of an experimental school demonstration project currently underway as part of the McDonnell Foundation's Cognitive Studies for Educational Practices program (see Mc Gilly, 1994)

5.2 More Specialized systems

5.2 The Jasper Woodbury Problem Solving Series

Authors
Cognitive Technology Group at Vanderbilt

Reference

CTGV(1992), The Jasper experiment: An exploration of issues in learning and instructional design. Educational Technology Research and Development, 40, 65-80.

CTGV (1994) From visual word problems to learning communities: Changing conceptions of cognitive research. In K. McGilly (Ed.), Classroom lessons: Integrating cognitive theory and classroom practice. Cambridge, MA: MIT Press.

Grade/Age Range

middle school students

Content domain

arithmetic story problems

Brief description of the system

Jasper provides a "video-based instructional macro-context for complex problem generation and problem solving" (p. ??), i.e., story problems which are enriched by a real-life problem solving context.

Which educational or cognitive theory is it derived from?

This system is derived from constructive theories, especially situated cognition and collaborative learning. Jasper can be applied within various teaching models, from those emphasizing basic skills first through structured problem solving, to guided generation of problems and subproblems. However, Jasper's features will only be fully used in less directive, generative contexts.

Instructional context

Intended for whole classroom and small group problems solving sessions; each problems takes at least two 1-hour class periods. Initially designed for 5th-6th grade math, it is now being extended upwards and downwards.

Where is the locus of control?

The locus of control is in the system which offers a video tape or disc presentation of a story; however, users can interrupt the presentation for discussion or search through it afterwards for specific data needed to solve the problem or subproblem. The degree of user control differs according to how the classroom is structured.

What does the system instruct ?

The system is designed to enhance conceptual and strategic knowledge: users need to identify and define problems, generate relevant subproblems, figure out relevant data for subgoals on their own. The goal is help students become independent problem solvers, capable of figuring out the information that is needed and seeking it out on their own. Having students work in collaborative groups is supposed to aid monitoring skills because they keep each other on track.

How is the content structured?
Pairs of related problems are presented together to foster transfer, analogous thinking. Content is not structured otherwise because the system is designed to foster open-ended problem-solving skills such as those one encounters in real-world settings. However, Jasper can also be embedded in basic skills curriculum to provide practice on previously learned component skills. Future work will extend the range of difficulty of problems: e.g., using whole numbers instead of decimals, less complex, alternative solution paths, etc..

What does the learner construct or manipulate?
Learners set up a solution space, subgoals of complex, open-ended problems. This approach is assumed to teach better reasoning, incorporating broad use of calculators and computer-based calculating tools (spreadsheets, graphing programs), and enables extensions to analog problems or even other domains.

How is prior knowledge used?
Solving these open-ended problems taps students' general world knowledge and a broad range of math skills, which mostly have been learned previously, though some may need refreshing. Sometimes new skills are instructed in a meaningful context.

Opportunities for transfer
All of these are up to classroom teacher:

- analog problems may be presented;
- students may be asked to make up analogous problems;
- an "adventure maker" is currently being designed to allow students to create their own adventures under given constraints (e.g., flying an ultralight with a 4-gallon, instead of a 5-gallon tank);
- extension problems are suggested to other domains: e.g., to historical or current events; extension videos are also being developed.

Amount and type of support, when provided

Support is provided by the teacher, or by members of the collaborative group, not by the system, and may range from very structured (e.g., setting up the problem with blanks to be filled) to the teacher functioning as a guide, model, and co-learner. At the outset the teacher often needs to supply a prompting question to suggest alternative solution paths to try; support may also take the form of structured exercises.

Range of tools that are available
Videodisc or videotape format. Videodiscs allow easy search, freeze-frame, random access. Computers are not required.

Forms and levels of interaction with tools
Users do not directly interact with the system beyond the usual VCR functions which allow accessing particular information (see above).

Errors and feedback
The authors assume that errors will be corrected by other members of the collaborative group or the class as a whole; they are treated as opportunities for learning. Feedback also occurs in discussion during which students are required to explain their solutions and justify their reasoning.

Interest, aesthetics
Lively, interesting story contexts; students seem very motivated and interested in the group problem-solving activity; all levels of ability get involved.

Assessment of learning
Assessment studies are in progress. Preliminary results (1992) indicate that Jasper works better in small groups than individual problem solving, and that students become better at detecting errors. Some evaluation studies are referenced in the1992 paper: e.g., a comparison of Jasper with structured exercises (to minimize errors) vs. student generated solution paths (see articles cited in this paper by Hasselbring et al.,1988; Van Haneghan et al., 1993).

General Evaluation
Although interaction with the system is minimal, the videos provide rich and challenging opportunities for group problem solving. However, the success of the Jasper system depends critically on teachers who are able to exploit its potential.

5.2.2 JANUS, a design environment for architectural design

Authors
Fischer, G., McCall, R., & Morch, A.

Reference

Fischer, G., McCall, R., & Morch, A. (1989). JANUS: Integrating hypertext with a knowledge-based design. In Hypertext '89 Proceedings, (pp. 105-117). Pittsburgh, PA: Association of Computing Machinery.

Content domain

This system is an example of the construction kit approach, which provides domain-level building blocks combined with a critic. Users can interact with the system, actually do programming without needing to learn programming language. They are dealing with familiar terms, and the system has the domain knowledge to correct design errors and to provide explanatory feedback (why a particular action is a poor idea, offer suggestions). The learning process is made more efficient and more effective because it takes place "on demand", while dealing with a particular task or subproblem. The learner doesn't have to have the knowledge beforehand nor to interrupt the problem solving to figure out how to access relevant knowledge. The content domain covered by JANUS - architectural design, specifically kitchen design - was developed as a demonstration project, but the ideas are broadly applicable to other, even fairly open-ended domains.

Which educational or cognitive theory is it derived from?

Meaning construction, guided discovery, situated learning, learning on demand when information is needed all characterize learning throughout the life span (as opposed to formal schooling), according to Fischer et al..

Instructional context

Individual tutor

Where is the locus of control? (e.g., open exploration, directed)

JANUS is not an expert system guided by top-level goals and designs. Instead, the user controls the system at all times: the critic can be turned off by the user and the system used only to construct a design. Likewise, a good design can be chosen from the catalog which requires only minor modification, thus activating few suggestions or criticisms from the critic. This approach aims to combine construction and argumentation (Hypertext network) which is relevant to the current construction task. The argumentative component can be explored in brief or at length by pursuing links to further information.

What does the system instruct

(1) Conceptual knowledge building in a specific content domain with explanations which focus on underlying principles.

(2) Knowledge of system tools and resources is also instructed.

How is the content structured?

The designer can either construct from scratch or modify an existing design.

What does the learner construct or manipulate?
To construct a new design the designer chooses building blocks from a "palette" forming a design unit and moves them into the work area. To modify an existing design the user brings one into the work area from a catalog which contains both good and poor designs. Poor designs especially help learning the design principles because they will elicit a large number of criticisms.

How is prior knowledge used/enhanced?
Learners can pursue problems at different levels of difficulty, self determined, or explore the argumentative function as desired. They can better exploit the high functionality of the system without having to first master complex tools. The system is able to accommodate a range of ability and knowledge.

Opportunities for transfer
Presumably transfer will be enhanced by understanding of underlying principles and by learning in a variety of contexts.

Amount and type of support, when provided
Support is in the form of feedback, both positive and negative, provided when the critic system detects a design problem. The critic acts like a coach, offering suggestions and explanation of principles underlying a design decision. Users can choose increasingly complex design problems, according to their own goals and fade out use of the critic:

- easy designs to get started: no need for prerequisite skills, such as system building;
- challenging but attainable goals: one can work in richer environments without interrupting the problem solving or construction to search for information; learners can gradually relinquish dependence on supports because they are also learning how to locate and use the relevant information resources.
- scaffolding, not only in graduated difficulty of the problems, but also in the complexity of concepts: not too much new information at once; abstract concepts are presented in a concrete context
- accommodates individual differences in background knowledge.

Range of tools that are available
The goal of all LOGO based systems is to make available the whole richness and power of the system, the idea of "no threshold, no ceiling", so that learners can advance through increasingly complex microworlds (Burton, Brown, & Fischer, 1984).

Forms and levels of interaction with tools
Construction kit

Errors and feedback (amount, type, when provided)
Errors are opportunities for learning. Feedback from the computer critic supports the learning process (see above).

Interest, aesthetics
Little information is provided, except to note that in informal assessment users found the system easy and fun to work with.

Assessment of learning
No formal assessment study has been reported.

General evaluation
The AAAI paper provides only a very general description of use and evaluation by amateur and professional designers; no specification is included of how their learning was assessed, though probably an opinion questionnaire was used. The following limitations have been noted by the system builders:

(1) JANUS only allows viewing at the room, not at higher or lower levels;

(2) it does not allow simulating the use of the design, a technique often used by designers;

(3) it does not allow designers to input their own goals, preferences, specifications for a particular problem, e.g., to manipulate competing goals such as cost and feasibility tradeoffs, thus it remains limited to abstract situations. Note, however, that these aspects are being addressed in extensions of the system.
Other problems with this approach:

(4) The system does depend on a diagnostic system, though not as extensive as student modeling. Nevertheless, this could be a huge amount of knowledge that needs to be built in, depending on the open-endedness of the domain.

(5) Knowing when to interrupt with a critique, how often, what feedback is needed are also a very complex issues. For example, sometimes it may be better to let users discover and remedy errors on their own. Can users also be expected to know how much information to seek?

(6) For what kinds of domains is this system best suited? It is probably not optimal for acquiring basic principles in a very open-ended domain.

5.3 Hypermedia/HyperText

Hypertext differs from linear text in that it provides many choice points from which the reader can branch out according to his or her interests or special needs. For such a system to be effective, good maps and navigational devices must be available. The advantage of hypertext lies in this tailorability to individual goals and requirements. There are some dangers, however. Hypertext allows readers to design their own text, to organize their own book. While this has some obvious attractions, organizing a text is no easy task, as any author can tell, and to put this burden on an inexpert reader is not without its risks. In many situations, the author knows best how to organize his or her text, and most readers can do no better than follow this organization, even when they have the opportunity to deviate from it (Foltz, 1992). In the worst case, the reader will become confused and lost, and empirical evaluations of hypertext systems have for the most part not shown them to be superior to linear text (for a review, see Foltz, 1992). However, there are exceptions. For certain tasks, a well-structured hypertext system can be much superior to a conventional book. Most notably, Superbook, a hypertext browser which is based on cognitive research and has been extensively and iteratively evaluated, has proven to be highly effective for locating dynamically needed information for problem solving tasks in various domains, such as chemistry and statistics (Landauer et al., 1993).

5.3.1 Cognitive flexibility and hypertext

Author
R. J. Spiro

Reference
Spiro, R. J., Vispoel, W. P., Schmitz, J. G., Samarapungavan, A., & Boerger, A. E. (1987). Knowledge acquisition for application: Cognitive flexibility and transfer in complex content domains. In B. K. Britton & S. M. Glynn (Eds.), Executive control processes in reading. Hillsdale, N. J: Erlbaum (pp. 177-199).

Spiro, R. J., & Jehng, J. C. (1990). Cognitive flexibility and hypertext: Theory and technology for the nonlinear and multidimensional traversal of complex subject matter. In D. Nix and R. J. Spiro (Eds.), Cognition, education, and multimedia: Exploring ideas in high technology. Hillsdale, NJ: Erlbaum (pp. 163-205).

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

Content domain
Hypertext, or random access presentation of text, is particularly suited for concept learning at advanced stages of knowledge acquisition when the learner is faced with more complex and ill-structured content, and applications to specific cases or examples are less straight forward.

Which educational or cognitive theory is it derived from?
According to the cognitive flexibility hypothesis, flexibility in the knowledge base is necessary in order to apply complex knowledge to specific cases in ill-structured, open-ended domains (e.g., medical diagnosis), since knowledge structures will have to reassembled in various manners depending on the dictates of the specific cases. These ideas are a version of constructivism which emphasizes the situation specific assembly and reassembly of components of prior knowledge. Accordingly, the knowledge acquisition process should support maximal interconnectedness of knowledge representations, whereas traditional modes of representation and learning tend to oversimplify and compartmentalize knowledge. Concepts with multiple connections in the knowledge base form a web-like network, or "criss-cross conceptual landscape" which is best supported by nonlinear presentation of subject matter such as that afforded by hypertext.

Instruction context
Individual tutor

Where is the locus of control?
Users choose their own path through the subject matter by accessing whatever topics they wish. Hence, the learning process is undirected.

What does the system instruct?
The focus is on forming linkages among concepts.

How is the content structured?
The content is organized into cognitively manageable chunks of information without oversimplifying the content. The implementation developed by Spiro et al. was designed to teach an advanced understanding of the firm, *Citizen Kane*. The system is organized around small segments, or minicases, from the film and 10 critical themes relevant to understanding each minicase. The system provides the student multiple perspectives with which to examine the minicases or use of a particular theme. For example, students can examine the various themes relevant to a minicase or search the minicases by theme or combinations of a theme, thus combining and recombining elements of the film according to their own particular purpose.

What does the learner construct or manipulate?
Learners thus structure their own conceptual understanding rather than learning information in a rigid, pre-organized form. They choose how to link elements of presented information, which, according to cognitive flexibility theory should result in the construction of a knowledge base composed of multiple interconnecting links to other concepts, e.g., cross references to other themes.

How is prior knowledge used?
Given that learners design their own learning path, this system draws heavily on prior knowledge, interest, and personal goals.

Opportunities for transfer
Spiro et al. claim that broader experience during the learning phase, e.g., by traversing through multiple perspectives on the subject matter, should facilitate applying the knowledge to novel cases. That is, multidimensional analysis supports multiply linked conceptual understanding and avoids rigid compartmentalization of knowledge. Thus the learner develops more efficient access to relevant knowledge in memory. In using this hypertext presentation learners are constantly required to apply new information to new cases during the learning phase.

Amount and type of support, when provided
Very little guidance is provided by this hypertext system. The only structure is in terms of how the content is decomposed.

Forms and levels of interaction with tools
Hypertext simply provides non-linear, random access to the material. The user chooses which segments of information to read in which order by pressing on topic buttons. Apparently there are no labeled links, instead they are implicitly formed by the student.

Errors and feedback
There are no opportunities for error correction or feedback within the system.

Assessment of learning
Assessment by Spiro, Vispoel et al. (1987) consisted in comparing a "criss-crossed" hypertext group of students with a control condition in which information was presented in a well-structured, linear textbook fashion. The hypertext group outperformed the control group on all six transfer measures which required applying the knowledge to new kinds of problems. However, the control group was better on tests of factual memory. The researchers concluded that their knowledge was structured too inflexibly to be easily accessed for novel applications.

General evaluation
The nonlinear presentation of material via hypertext potentially does encourage more constructive, inferential kinds of processing, due to the necessity of figuring out the relationships between segments of information. It is of course true that these are the kinds of processes required for representing knowledge at the level of the situation model, as opposed to a more superficial textbased understanding. However, the lack of guidance can be problematic for all but the most advanced and self motivated learners: What is to prevent learners from constructing the wrong kinds of links

between concepts, i.e., to construct an inaccurate situation model? And what is to prevent students from reading the information in a thoughtless manner, i.e., without really thinking about the ways concepts, or minicases and themes, could be linked? Thus, passive reading is just as possible in an unguided hypertext system as with linear text, and the consequences of unstructured content may be much more damaging.

In a recent study by Shapiro (submitted), the beneficial effects of a nonlinear text presentation did not extend to tests of learning involving inference generation, even though the hypertext groups had developed more associations between concepts than the linear text group. Clearly, a good deal more and very careful research is required to determine whether, under what conditions, and for whom hypertext presentation may result in better understanding and learning. In particular, differential effects of readers' background knowledge should be considered, since high-knowledge individuals may well respond differently to the lack of structure than low-knowledge readers, as was the case for coherent and less coherent text (see McNamara et al., in press, and other studies discussed in section 4.1.4.3).

6. Evaluating Interactive Media for Education

6.1 Defining the context of evaluation

Evaluation of educational methods and tools is, as Reeves (1990) remarks, inherently dependent on historical, political, and situational circumstances. An evaluation of the use of a particular medium, say the radio research or the 1950s or the television research of the 1960's (e.g., Hovland, Lumsdaine, & Sheffield, 1949; Schramm, 1977), had to justify the investment in the medium to educational administrators. This meant several things: the evaluation had to be expressed in a language meaningful to these decision makers; evaluations were based on conceiving teaching and learning as disseminating and taking-in of basic facts and knowledge, and the medium had to be proven more efficient, or at least more cost-efficient than traditional classroom lessons. There was a strong assumption that general knowledge, such as language skills, historical knowledge, math skills, and basic science facts had and could be internalized by individual learners to prepare them for the application of these skills and knowledge in the professional world. There also was (and still is) an assumption that knowledge of this type could be measured in standardized, general tests.

The following criticism of these studies, put forward by Richard Clark (1983), imply these assumptions, and point to problems with this type of research:

"The best current evidence is that media are mere vehicles that deliver instruction but do not influence student achievement any more than the truck that delivers our groceries causes changes in our nutrition. ... It seems reasonable to recommend, therefore, that researchers refrain from producing additional studies exploring the relationship between media and learning unless a novel theory is suggested."

Clark was not the only reviewer to lament the inconclusiveness of evaluation studies based on the paradigm of comparing a medium of interest with traditional classroom lessons. He is joined by others (e.g. Cronbach, 1975; Hoban, 1958; and Reeves, 1986, 1990). As sources for the inconclusiveness of the studies, confounds, such as teaching method and novelty effects, and inappropriate manipulations and measurements are discussed. However, the goal of evaluation to convince decision makers to invest in a medium as a superior method of knowledge dissemination did not receive criticism, as it defined the proper political context for these studies up until the eighties, and even in some senses until today.

In the last twenty years, the cultural and political context for which the educational system should prepare has changed dramatically. A large and growing proportion of people now live and work in electronically mediated environments. Job-relevant information abounds, and changes constantly. Information can be accessed instantly even from remote locations, and it can be shared between coworkers in geographically distant locations. Work in the information age does not rely as much on the retrieval and application of general or specialized sets of knowledge from the minds of individuals. Instead, precise and specific information can now be retrieved electronically by anybody having access to the resources, or it is embodied in tools, such as CAD tools, or even in simple functions, such as spell checkers.

This leads increasingly to the elimination of jobs that ask for the application of rote skills and knowledge in paper and pencil environments, where product cycles were slow, and the need for sharing of the results infrequent. Today, many tasks can be completed instantly and automatically so that the main work emphasis is at the level of communicating the results, and negotiating decisions based on it. Thus, collaborative use of external knowledge repositories, for joint construction of problem solutions is and will be central to the work life. Industry leaders are increasingly emphasizing this shift in job skills, namely, a need for computer literacy, and the ability to collaborate, and to communicate successfully with the assistance of electronic media (e.g. Time Magazine, Special Issue: Welcome to Cyberspace, Spring 1995, pp. 49-51).

This situation defines part of the socio-cultural context for developing and evaluating educational media and methods today. A second educational need is remedial. Especially the public educational system has been challenged recently with the task of providing adequate basic education to all students. It seems that the 'traditional classroom lecture' does not meet the changing needs of a large proportion of students, especially students whose basic educational needs are not met by their families. Another goal of educational change therefore is to provide learning environments and methods that will integrate the activities of a diverse student body and engage all student in meaningful and knowledge constructing tasks.

6.2 Three goals of evaluation

6.2.1 Measuring the desired effects

How does this context define the goal for evaluation of teaching methods and media in the classroom? At first, researchers and educators will have to continue proving that electronic media, computers and access to networks are desired, or cost effective teaching tools. Even though computers, and even networks have been introduced into a large number of classrooms (e.g. Time Magazine, Special Issue: Welcome to Cyberspace, Spring 1995, pp. 49-51), public educators continue to struggle justifying updating of quickly outdated equipment (e.g. Blacksburg paper, Winona newspaper clippings). But, the question is also how to embed computers usefully in the classroom, how the computer will change the classroom interactions, and how these anticipated uses will lead to the type of skills that industry expects their new generation of employees to bring into the workplace. Furthermore, there are many systems and services that can be installed on computers and networks, and there is a need to decide which ones will influence classroom interactions in a desired way. There is also a need to show how the use of such systems influences students achievement differentially, and whether there is a chance to increase the participation and achievement of low-achieving students.

6.2.2 Describing the patterns of use

Another aspect of evaluation concerns itself with the use-aspect of systems. In other words, to design multimedia systems successfully, designers as well as educators will need to know how a system will be used in a certain situation. This question is especially important for systems designed from a constructivist perspective, because many of the systems (see Section 5) above, don't force a student through a set of drills, but enable the student to create documents, programs, or find their own way through a documentation (e.g., Bruce & Rubin; diSessa; Shapiro). On the other hand, systems are not necessarily designed without intended uses. For example, in the Quills writing package, designed by Bruce and Rubin (1993, p. 45), educational goals (such as learning to plan) were implicit in the provision of software features (such as a planner, that helps in structuring a paper). It is necessary to know whether these features are used at all, in which situations, by whom etc. For the designers of the software it is also important to know whether there are usability hurdles to the use of any functions.

6.2.3 Relating patterns of use with effects

Finally, to learn about the design of interactive educational environments in an optimal way, system designers as well educators need to know which particular uses of a system by which users and in which environment leads to which particular result. An accumulation of this type of information enriches our knowledge about known methods of system design and use to achieve specified learning outcomes. As of now, there are still few empirical studies that address this causal connection in a satisfying way (but see Reeves, 1993).

6.3. Methods of evaluating learning

In this section a range of measures and methods to achieve the three goals of evaluation will be suggested. The list included here is not and can not be exhaustive, as many of the variables and behaviors that can be measured and observed depend on the particular system under investigation. What we are trying to convey is the idea that for a study to be conclusive, researchers will have to be both creative, and analytical. They will have to analyze the possible uses and effects in an appropriately detailed way, and they have to be creative in inventing measures that tap those variables appropriately. The discussion here is not meant to provide a complete cookbook, but it should provide some examples and issues to get started.

The lists provided below are organized along the following lines: A general method or measurement is listed and explained briefly, including the reason for including such a measurement. When available, a brief example from the literature will be given.

6.3.1 Measurement of effects of using the system

6.3.1.1 <u>Standardized tests and measures</u> (e.g., SAT scores, ACT's).

What is it
Standardized tests, such as math and verbal SAT scores and various reading comprehension instruments are designed to test skill level in a generalized skill or knowledge area. Tests like this are used nationally, and they are usually designed to avoid local or other biases that are other than skill related. Standardized tests usually come with interpretations for specific scores, that is there are guidelines that rate performance compared to a national level.

Reasons for using it
They don't have to be designed and are easily administered. They are designed to be administered repeatedly without inducing test-related learning effects (several versions of a test). Educational or grant agencies may request a measure that allows comparison with a known standard. It may serve as a good baseline measure of performance, and it may be interesting to see the differences between outcomes in these general and more specific, tests, designed to measure performance of particular knowledge or skills (see below).

Problems
These tests are general purpose instruments. They may not test specific learning results. They are fact oriented, not process oriented, and therefore they may not capture changes in motivation, approach to learning and knowledge oriented tasks. They have been criticized for being culturally biased. The may be appropriate for selection based on comparison with a standard, but they do not necessarily allow for meaningful interpretation of the acquired knowledge or skills.

Recommendation
Use for documentation and backup purposes. Use to compare achievement of treatment vs. control performance. Use to track change in performance over time. Supplement with more specific tests that measure other more interesting aspects of learning.

Example
Scardamalia et al. (1994, see Section 5.1.2) used the composite math and language skills Canadian Test of Basic Skills (CTBS) to demonstrate that CSILE students were doing at least as well as students in a more traditional classroom. Results showed that CSILE students had an advantage with respect to verbal skills, but not with respect to math skills, as expected. Explanations for these differences were gained from other, more specific measurements (see below).

6.3.1.2 Simple factual knowledge

6.3.1.2.1 <u>Recall, recognition.</u>

What is it
These are classical tests of memory for declarative information learned from texts. (e.g., van Dijk & Kintsch, 1986, or Welsch & Kintsch, 1989). In recall, subjects are asked to write down or verbally recall as much as they can from the studied material. Recall measures can be used to estimate how much information has been retained from a set of material. Various coding schemes can be used to classify the recalled information with regard to its position in the text structure. In recognition, subjects have to react to

specially crafted items, and verify that this is a true or a false statement, according to previously studied material. Recognition tests also measure memory for declarative information. For this measure, recognition items need to be constructed. Recognition items can correspond to the studied material in various respects, they can be verbal items, paraphrases, or sentences that contain true inferences, as well as items representing false information. Recognition rates associated with various classes of items can be used to estimate the retained knowledge on different levels of representation: surface information, propositional representation, or a representation of a model of the situation described in the material (for a detailed explanation of the measure, see Welsch & Kintsch, 1989).

Why use it

These are important measures to use when the goal of an instructional system is the construction of declarative structures. Items can be crafted to test for different levels of learning, especially, whether students are able to actively use the presented information for decision making or inferencing. Many hypertext or multimedia applications have exactly this goal in mind, and recall and recognition methods might be the right measures for these situations.

Problems

Scoring of recall protocols and the crafting of recognition items may be very time intensive, depending on the length of the recall protocols and the number of classifications used. Recall may only measure the surface representation of what was learned, and not necessarily how the knowledge was integrated into an overall knowledge structure. Both, recall and recognition only measure the net result of a learning episode. They do not directly lend themselves to interpretation of used meta strategies, or learning methods, and they do show, how and if the acquired knowledge can be used flexibly in problem solving (e.g., Mannes & Kintsch, 1987).

Recommendations

Looking at recall and recognition scores alone might not be very interesting; it is very important to compare across different presentation versions of a system, or to correlate recall and recognition rates for various levels of information with variables that describe the mode of presentation (e.g., was hyper-linked, presented in text format, presented in graph format, presented as simulation, was in the highest level of the hypertext structure, etc.). It might be interesting to use these measures at various forgetting intervals, because the advantages of some presentation methods might lie in better long-term retention of a certain type of knowledge

6.3.1.2.2 Measures of conceptual structure.

What is it

In these tasks, subjects are usually asked to respond to items containing single concepts, such a words, phrases, or pictures. In one type of task, cued association, subjects are shown a list of concepts (usually from the material studied) and asked to say the first association that comes to mind (e.g. Ferstl, & Kintsch, 1991). If the same list of items (in different orders) are presented before and after studying a set of materials, differences in the structure lead to conclusions about a change in the conceptual structure that makes up an individual's declarative knowledge in that domain. Similarly, subjects can be given a set of cards corresponding to single concepts, and asked to sort them into meaningful groups. Changes in groupings can again be used to determine changes in conceptual structure (Britton & Gulgoz, 1991). Several statistical methods exist to evaluate these changes numerically.

Why use it

These measures are especially interesting in situations where the goal of an instructional method is to change a previous conceptual structure, or to show that a method leads to a good integration of new knowledge into an old structure, because an assessment of structures can be made before and after studying of material. This type of result could not be gained from recognition or recall measures, for several reasons, such as test-learning from repeated exposure to the material, and the fact that a text can not be recalled before it was read, even though the concepts in the text maybe known in some way.

Example

A very creative and informative use of a cued association test was made in a study reported by Shapiro (1994). In hypertext research the claim is often made that presenting material in a flexibly linked web of conceptual nodes and links between them, will impart a similar knowledge structure into the students that study in this type of environment. Shapiro's project was concerned with supporting this claim, by comparing learning from different hypertext systems that implemented different links between concepts. After studying the domain in this way, her subjects answered to a cued association task, where they were given topic names from the system and had to answer with associations that immediately came to mind. The given associations were than categorized by whether they were contained in textual links only (where the two concepts were included in the same sentence), or whether the link was also implemented in a hyper link. The results from this analysis showed that concepts linked in the text AND linked through a hyper link had a much higher probability of being recalled than concepts that had only been mentioned together in the text. Comparing a hypertext version that implemented a typical hierarchical text structure with more flexibly linked presentations of the material led to more associations being formed in the flexibly linked versions than in the hierarchically linked version. This use of cued association avoided the difficulties of interpreting the implied conceptual structures, but showed that particular structures of hypertext can indeed influence the buildup of knowledge in a characteristic and positive way.

6.3.1.3 Application of factual knowledge.

- inferences
- problem solving tasks
- analogies.

What is it

These measures ask students to draw on their newly acquired declarative knowledge for solving a problem in the domain, making inferences, or using it in analogies. Inference sentences can be constructed similar to recognition sentences (see above). Or, carefully crafted questions can be asked that elicit whether students have actually made a connection between two assertions given in a text. Problem solving tasks usually ask students to provide a solution to a problem described to them. For example, if students study some material on causes of the greenhouse effect, then a problem solving task would ask them to solve a particular problem in this domain that was not directly discussed in the material, but that should be solvable on the background knowledge provided in the material. Analogies, are a specific case of problem solving, in which a general principle learned in the context of one domain can be applied in another domain to solve a problem. Flexible and appropriate use of analogies has proven to be especially difficult for students (e.g. Ross; Holyoak). Spontaneous use of appropriate analog structure is therefore a very good indicator of the buildup of abstract and flexible memory structures.

Why use it

These measures address exactly the type of flexible knowledge use that hypermedia systems and collaborative learning environments claim to support. Rather than just testing whether knowledge has been stored, performance on these measures let us know how deeply is has been processed. Deeply processed knowledge should be well integrated into an existing knowledge base, that is, it should be accessible using many different cues, and usable in many contexts. Performance on inference, and problem solving tasks shows to what degree this goal has been achieved.

Problems

Constructing sensible inference and problem solving material is difficult and requires a good sense for what can be asked from a set of students. It is easy to make the questions too difficult and produce a floor effect. Material should be pre-tested and construction can be time consuming.

Recommendations
Work closely with teachers or educators on constructing good and sensitive test material. When not sure, pretest material with small pilot samples. It may also be interesting to collect on-line verbal protocols from students trying to solve these problems. This might provide direct evidence for the types of knowledge that they are using in solving it. Finally, for a similar reason, it is useful to combine knowledge application tests with factual knowledge tests (see above). This enables researchers to see whether knowledge simply cannot be recalled, or whether it just cannot be used out of the direct learning context.

Example
A paper by Brown and Campione (1994) discusses the use of problem solving and the use of analogy in evaluating a collaborative teaching technique, reciprocal teaching (see chapter 2 above). Problem solving questions, for example, were to design a novel animal, perfectly suited to a given environment (application of knowledge of evolutionary principles). The answers were scored according to taught principles: application of taught principles, generalization of principles to invent new similar ones, etc. Teachers and researchers also analyzed the student's processes when processing text. After reading portions of expository text, students were asked to give answers to simple fact, inferential and analogy questions, furthermore the type of explanations given to these answers was scored. The results showed that students did not improve on comprehension of simple facts, but that they did improve in their ability to use that knowledge flexibly to draw inferences and analogies.

In a very different study, Gräsel, Mandl, Fischer and Gärtner (1994) evaluated the use of an interactive computer-based learning environment, THYROIDEA, that teaches medical students the knowledge needed to diagnose a dysfunction of the thyroid glands. As students are presented with more and more information about a case, they are asked to answer problem-related questions at different points during the presentation of the case. A 'coach' checks these answers and gives feedback about their accuracy. Students also have the opportunity to consult an expert segment about additional information on the symptoms. At the end of the program, students are asked for a final diagnosis of the case. In addition to other measures, these authors used the quality of the final diagnosis as an application of the factual knowledge to a problem solving situation as one criterion to evaluate the performance of the system. One interesting result of this study was that the use of the feedback to correct false answers was positively correlated with a good diagnosis at the end of the study.

6.3.1.4 <u>Simple procedural knowledge: problem solving</u>. Testing for this type of knowledge assumes a different type of knowledge representation. All previous tasks assumed that the knowledge to be internalized or accessed was of declarative format, that is, some types of concepts, interpretations of concepts, or high-level reasoning strategies. However, many learning curricula focus on the learning of procedural knowledge, that is, on knowledge of how to do a certain class of tasks. Even though learning theories generally assume that procedural knowledge is usually acquired through some type of declarative representation first (e.g. Anderson, 1987; Fitts, 1967), the desired product is a quasi-automatic application of specific procedures that allow for fast and error-free application of a skill. Examples for such problem solving strategies are procedures for math skill (Van Lehn - addition; Anderson & Koedinger - geometry; and Anderson; Pennington for low level programming and debugging skills). Procedures as such are usually acquired by repeated practice of a battery of identified subskills, feedback after an error has been detected, and then finally application of the subskills in more general task environments. These are the types of skills that Intelligent Tutoring Systems develop and support (e.g. Anderson, Lesgold,). Even though our report aims at describing systems that support the acquisition and flexible use of declarative knowledge, a brief section on testing procedural knowledge is included for completeness.

What is it

Problem solving tests usually ask for the solving of problems in a relatively narrow domain that the students were especially trained in. For example, students might have just gone through a training procedure on simple addition. In general testing then involves a battery of addition problems within the range of difficulty that was trained for. Measurements included the error rate, the speed of solving the problems, analysis of problem solving traces, and analysis of typical 'bugs' within those problem solving traces. Intelligent tutoring systems usually maintain a student model that traces performance on all these criteria. Students are only advanced to the next level of practice when they have reached a satisfactory performance in the next lower skill level. Another method that is very popular is having students 'think out loud' (Ericsson and Simon) while problem solving. Taking verbal protocols gives access to the students problem solving and reasoning strategies, especially when the to be acquired skill is still in the declarative phase of development, and therefore it is possible to decide why a problem could not be solved (missing information, buggy problem solving strategy, memory failures etc.)

Why use it

Simple speed and accuracy measures can lead to conclusions about whether a skill has actually been acquired, and what stage of acquisition it is in. Verbal protocols, analysis of problem solving traces, etc. lead to a diagnosis of where skill deficiencies occur, and can be used directly to enhance the underlying student model, or the curriculum.

Problems
These measures indicate whether the method or model teaches what it promises. They do not test whether the trained skill can actually be applied in a situation external to the tutor or class setting, that is whether students will be able to recognize contexts in which the trained skills are applicable.

Recommendations
These types of tests are a must to assure that a minimum of skill acquisition has been achieved. Certain basic skills (such as math skills, literacy, basic programming concepts and procedures) are and will be necessary knowledge in the future. However, acquired skills should also be tested 'out of context', applied to problems that require transfer to make sure that students have acquired something useful in real-life situations. "Out-of-context" and transfer tests are discussed below.

6.3.1.5 <u>Application of procedural knowledge to 'new problems'</u>.

What is it
Transfer problems can be given at varying levels of difficulty, where each level determines a higher level of generality of the skill and flexibility in using it. These types of problem solving tests ask to apply procedural knowledge acquired in one type of task to a new problem domain. Let's say procedural knowledge about multi-column addition has been learned in the context of one type of application domain, and is tested in a very dissimilar application domain. A far transfer test would be to present a problem one of whose subproblems affords an addition procedure without explicitly asking for it. The addition training would definitely prove to be successful if students could spontaneously recognize the type of problem and apply their knowledge without the affordance characteristics of the 'word problem', or 'tutor lesson' context. Another type of transfer problem asks students to apply particular concepts embedded in a skill to a different task. For example, one could ask students who have been trained to write program code to now debug somebody else's code, or one could ask students that have become proficient in multi-column addition for a solution of a multi-column subtraction problem.

Why use it
If the educational goal is to impart basic skills that are widely applicable and can be flexibly used, then one should make sure to include situations to test this in the evaluation. Students may be able to produce answers to satisfy a teacher or tutor if the context is given, but they might not be able to export that skill to another situation. Similarly, if a training procedure has indeed involved some 'deep thinking' about a skill, rather than just rote practice, students might be able to solve a similar problem that draws on the same knowledge, but not on the same procedures (Pennington & Nicholich).

Problems
True transfer tasks may be difficult to design. It may be difficult to set up a situation, so that the context cannot be used to be a cue for what is expected. It may seem too cumbersome to take students out of the learning context (classroom, computer based instruction, word problems etc.) into another, to test how these skills can be applied.

Recommendations
If the evaluation is done as part of a class curriculum, it may be possible to measure some curriculum activity that emphasizes a different educational content (e.g.,. a history session, or a biology project), but can be used to measure a skill learned in a different class or different subject area. This would set a different context (content of class, teacher). This affords close work with the teachers in a school where the testing of a system is done.

Example
A good starting point for 'out-of-context' testing would be the design of the Jasper series (The Cognition and Technology Group at Vanderbilt, 1992; 1994, see description of the research program above in Section 5.2.1.). Jasper problem solving contexts involve real life problems, which are introduced in an adventure story video. Students are invited to identify with the protagonists' goals and solve a problem for them that involve many subproblems of differing contents. Even though the Jasper videos are used as a type of instructional scaffold, one could easily imagine using them as a testing ground instead.

Pennington and Nicholich provide a good example of using a 'reverse skill' as a transfer test after training on an intelligent tutor. Here, the performance on the transfer test does not serve to evaluate the tutor, but to test a particular learning theory. However, performance on reverse skill could easily be use to test for differences for training on two different types of tutors or training methods.

6.3.1.6 <u>Higher level knowledge (strategic or meta knowledge)</u>

- planning strategies
- metacognition/self-monitoring strategies
- advanced comprehension strategies

What is it
These are the domain independent general problem solving strategies that have been very difficult to induce and test in past research (e.g. Singley & Anderson, 1987). However, many constructivist theories have the acquisition of such knowledge as their goal, which means they should at least attempt to show that methods suggested by them are approaching these goals. Planning strategies are general approaches to a problem, namely to recognize that there are several subproblems to solve, and to determine the interdependencies

between the solutions to these parts. They could also include the skill of determining that different people or groups of people should work on the subparts and report to each other for solving the overall problem. Self-monitoring strategies or advanced comprehension strategies help students to determine that they have reached an impasse either in comprehension or problem solving. If such an impasse is detected, expert problem solvers have analytic skills to determine what the current impasse is resulting from. It could be the lack of a piece of information, it could be the lack of a skill, or ambiguity in the information provided. One good way to monitor the application of these high-level problem solving strategies is to observe students" behavior, elicit verbal protocols, or even prompt them for explanations of a particular problem solution. Test problems or texts should have known problems in their representation, so that strategies to fix these problems can be expected at certain points in the problem solving procedure.

Why use it
As mentioned above, constructivist theories claim to support the acquisition of such high level strategies for learning to learn, so it is important to test whether they are really approaching this goal.

Recommendations
To elicit higher level problem solving strategies, there should be a clear definition of the strategy to be elicited. For example, a test for meta strategies involving text comprehension would involve a text with known comprehension difficulties, or a test for good planning strategies would involve the solving of a complex problem with many subgoals and interdependencies between subsolutions. Strategies can be elicited by verbal protocols, or by having several students work on a problem. Their conversation about the problem can then be analyzed.

Example
To test the effect of the reciprocal teaching strategy, Brown and Campione (1994) gave their students difficult expository texts outside of their area of study and asked them for facts, inferences, gist, etc. at various points during the reading of the texts. The students' responses to these questions showed that students who had been using the reciprocal teaching strategy, improved especially on the inference, gist, and analogy questions.

6.3.3. Linking use of a multimedia system and effects on learning

6.3.3.1. **Exploratory studies**. If the study questions are open-ended, that is, if there are no clear predictions about how a system might be used, and which of the functions will lead to some type of learning result, an exploratory research strategy is recommended. In an exploratory trial, a wide range of information should be collected to allow for discovery of unexpected variables.

With respect to usage patterns, video-taping all interactions with the system rather than observation only is a very good start. Having a video tape of the interactions available makes it possible to identify interesting behavior patterns in a first step of analysis. Once several interesting types of behavior have been categorized the tapes can be used to collect more details of these behaviors (frequencies, timing, etc.). If data are collected through observation of ongoing behavior (without recording), it is often difficult to collect accurate numeric information needed for statistical analysis. It is also more likely that interesting but unexpected results would be missed.

If little is known about who will profit most from using a system (or who will use it in a particular way), it is also important to collect data from a wide range of participants and to collect a wide range of demographic information.

With respect to measuring the effects, it would also be useful to develop a range of measures, unless there are clear theoretical or empirical a priori reasons for concentrating on a specific measure. If a particular type of learning is the goal of the system design, it would be useful to have some direct learning measure (like recall, or problem solving ability), and also to include a few indirect measures (transfer, meta-strategies via verbal protocols) or a delayed test condition. With any given learning paradigm it is likely, that differential effects will emerge for these different measures (e.g., Schmidt and Bjork, 1992). Spreading measurement techniques in this way may help to discover where exactly the beneficial effects of a system may be.

The same tactic would also apply to other types of measurements, for example in measuring the quality of collaboration. As long as the hypotheses are vague, it makes sense to collect a broad range of information to make sure that no interesting effects are overlooked.

To analyze these data, correlative data analysis techniques, such as standard regression techniques, correlations, and factor analyses can be used. Even though direct causal interpretations are not possible with these methods, they will help to identify interesting relationships in the data that can then be researched further with controlled designs. Unfortunately, correlative data analysis techniques can only be used with a relatively large number of subjects. Reeves (1993) suggests similar types of analyses techniques, and Shute (1993) provides a great example for the advantages of using correlations of actual use of functionality to explain performance.

In her study, Shute (1993) compared two different versions of an intelligent tutoring system that teaches electric circuit design. In both versions, students are solving problems in the domain that are selected by the tutor based on previous problem solving performance. Students also have access to a window with definitions of terms (e.g. 'voltage'). Another window gives access to simulations of circuits that can be used to take measurements or to experiment in the domain to extract additional knowledge. These two windows are accessible to students using both versions. The single difference between the two versions is the type of feedback that is given to students after a problem solution has been submitted to the system. In the rule-application version students are notified about mistakes, and the feedback also includes the rules that had to be applied but were violated. In the 'induction' version, students are only told if they solved the problem correctly or not, and students are left to induce the rules themselves.

In her experiment, Shute collected data from over 300 subjects over seven days. She collected a range of data describing the subject population, such as demographic data, pretests, determining declarative and procedural, domain relevant background knowledge, and cognitive ability measures, such as working memory capacity and information processing speed. Furthermore she collected, for each subject the frequency of use of the declarative and procedural exploratory features of the system. In order to measure the learning effects, she combined several posttests into one learning score, and she defined learning efficiency over the time needed to complete the tutor, and the number of problems needed to reach criterion (the more mistakes subjects made, the more problems were presented to them). The core of the statistical analyses are three multiple regressions, using performance on the combined posttest score, efficiency measured by time on tutor, and efficiency measured by -number of problems solved as the three dependent variables. The independent variables were posttest scores, version (induction vs. application), and the frequencies of using the declarative and procedural exploratory features of the system. Without going into the details of these analyses, Shute found a range of interesting results. Overall, subjects performed better in the rule application version, where they did not have to induce the rules of the domain. Secondly, the more the subjects made use of the declarative exploration feature, the better their performance overall. Procedural exploration, on the other hand, seemed to be related to poorer performance. However, there was also an interesting interaction in that procedural exploration in the rule-induction environment was related to improved performance, whereas it was related to depressed performance in the rule induction version of the system.
These types of results, coming from a multiple regression analysis don't necessarily lead to clear causal interpretations, but they suggest interesting hypotheses to follow up in further studies or to consider in the design of systems: Students who like to explore more are not generally better learners, but they might be better suited to learn in a open environment with little specific guidance; procedural exploration may actually hinder performance when all necessary information can be found in the immediate performance;

exploration of declarative and procedural aspects may have different effects on acquisition of requisite knowledge.

In a simple study using one dependent measure and one independent measure (version a vs. version b) this important information would have been lost, and no explanation for the differences in performance in the two studies could have been offered.

7. The Value of Theory or Hypothesis Guided Design

The most critical lesson from constructivist theories is that computer educational tools should treat users as active agents in the learning process, that deep learning requires situations where learners have to construct knowledge for themselves. You have to really own the new knowledge to be able to use it. Computers can make available a range of valuable tools to aid difficult conceptualizations and to encourage multifaceted learning (e.g., by transforming a textual description of a process into a dynamic display). Further, they can also provide supports for higher level, analytic thinking processes (e.g., by prompting the learner where to search for relevant ideas). However, both roles depend crucially on careful task analysis to select the right tool for a particular learner and a particular task.

Beyond their usefulness for individual learners, multimedia education systems may function as instruments of change in the classroom. Many of the programs we have reviewed are designed for or certainly are suitable for working in collaborative groups, ranging from two-to-three persons to a whole classroom and thus serve to break down the communication barriers between teacher and students that characterize so many didactic settings and that seriously interfere with getting students to think reflectively, to analyze ideas, to criticize and justify opinions.

We end this review with a plea for the use of theory in the design of instructional systems, including multimedia-media instructional systems. Both our general discussion and the analyses of particular systems and their performance suggest that it is impossible or at least very difficult and resource consuming to test and evaluate each component of a system in the field. Laboratory studies have their own limitations. Of course, we cannot do without either one. We need the field studies, the careful evaluations, however expensive and time consuming they might be. Further progress in our understanding of these systems depends on such work. But we also need quick and practical alternatives.

The theory of learning sketched in these pages can function as a guide for many design tasks. It will not be an infallible guide because, as it is obvious from the preceding discussions, learning is a very complex process, and its outcome depends on such a large number of factors that we can never hope to control them all. However, if one has a general understanding of the principles of learning and instruction as outlined here, as well as an appreciation of the nature of the learning task involved, one ought to do quite well in designing instructional systems according to those principles as a first approximation. Then, relying on the kind of informal observation and evaluation that is always possible, adjustments can be made, and hopefully, with a few iterations, a usable system can be developed. Nevertheless, a thorough task analysis is required in order to determine what type of learning is involved and when and what type of multimedia support would be most beneficial. As we have discussed above, tasks that are merely procedural versus those that can be learned in an apprenticeship situation, or by telling a story or showing a movie, each make their own kinds of demands.

What we have focused upon here are tasks requiring rational thought and symbolic representation. These tasks are the most difficult ones for students of all ages and educational levels; these are the ones that many instructional systems must focus upon. The principles of learning described above, and the systems that we described which embody these principles in one way or another, can be a guide to the design of such instructional systems.

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