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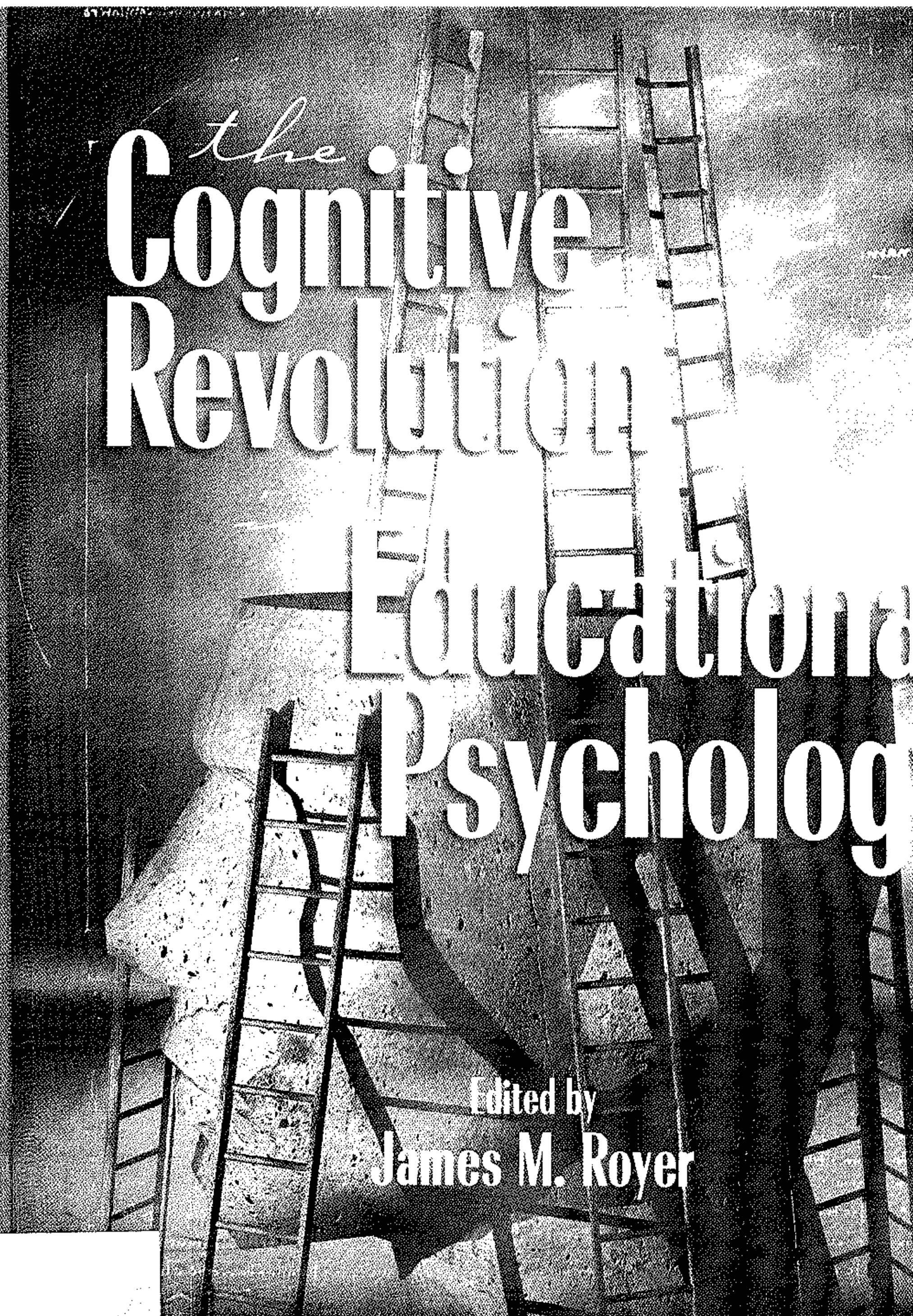

the Cognitive Revolution in Educational Psychology

Edited by
James M. Royer

A VOLUME IN
CURRENT PERSPECTIVES ON COGNITION, LEARNING, AND INSTRUCTION

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CHAPTER 1

THE COGNITIVE REVOLUTION IN EDUCATIONAL PSYCHOLOGY

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ABSTRACT

This chapter serves as a foreword to the remaining chapters in the book. The chapter provides a description of the cognitive revolution, which began in the 1950s and reached full fruition in the late 1960s. The term "cognitive revolution" began to be used to take advantage of an analysis of scientific revolutions in general that was developed by Thomas Kuhn. The next section of the chapter describes how some aspects of the cognitive revolution seem to fit Kuhn's analytic framework, and others do not. Following this analysis, the chapter turns to examining the impact of the cognitive revolution in educational psychology as illustrated by the remaining chapters in the book. Each of the chapters is briefly described and the end of the chapter comments on the likely direction the revolution will take in the future.

The cognitive revolution began on September 11, 1956. That at least is the date picked by George Miller, one of the principal instigators of the revolution (Miller, 2003). The occasion was a symposium at the Massachusetts

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CHAPTER 9

RESEARCH IN INSTRUCTIONAL TECHNOLOGY

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ABSTRACT

This chapter traces the changes in instructional technology from the early days of instructional practice based in behaviorist theory, to the social cognitive and constructivist approaches that are currently in vogue. The affordances and uses of different technologies for educational purposes, as well as the theoretical movements that have inspired instructional techniques and new technological developments, are discussed.

The last half of the 20th century saw an impressive array of educational technologies introduced to the classroom. In the 1950s and 1960s, filmstrips and movies brought sound and moving pictures into the classroom. The overhead projector, first developed for military training, allowed

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teachers to face the class instead of the blackboard, and also create reusable teaching materials. The photocopier began to replace the mimeograph machine, enabling teachers to distribute copies of material from newspapers, magazines, and books, and also to design their own units and assessments. Cold war schoolchildren watched the broadcast launches of NASA's first Mercury manned space flights on small televisions in lunchrooms and auditoriums. In the 1970s and 1980s, the invention of calculators promised individual access and mobility, and television found its natural partner in the videocassette player, creating a market for educational video content that was less expensive and easier to keep current than film collections. The introduction of personal computers dominated the 1990s. Apple II computers were replaced with Macintosh and DOS/Windows platforms that were distributed in laboratories and classrooms and a new industry arose: educational software titles. At the turn of the millennium, global, local, and wireless networking dominated the educational technology effort as network devices such as laptop and handheld computers gained commercial popularity.

The introduction of each new technology has led to a great deal of optimism that it would lead to substantial improvements in educational outcomes. Those products that were marketed to the general public, such as the television and the personal computer, were objects of great techno-optimism and were promised to forever change the way we learn. However, no grand improvements in student learning were seen simply due to the introduction of these technologies into the classroom. An important lesson to take from the past few decades of research on instructional technology is that technology in and of itself does nothing to improve learning or instruction. Technology does not eliminate the issues of the classroom, but instead offers a new means of approaching them. Surprisingly, despite the fact that computers have been in classrooms for close to 20 years and that children are highly familiar with computers and use them daily from very young ages, there does seem to be a "novelty" effect for technology even now (see Clark, 1983, 1985; Kozma, 1991, for discussion about the motivating effects of computers). Children seem to like to use technologies in the classroom, and computerized instruction can lead to increased levels of interest and engagement among students. However, interest alone does not guarantee positive learning outcomes. Rather, it is a question of when and how technology can be incorporated and leveraged into the educational process to best support learning.

The goal of this chapter is to trace the theories of instructional technology from the early behaviorist approaches to the present, to highlight the ways that the cognitive revolution has affected the way technology is used in instruction, and to reflect on several shifts in instructional theory and practice that may in part be due to the introduction of the new resources.

THE BEHAVIORIST LEGACY

The earliest approaches to the use of technology for educational purposes were rooted in behaviorist theories of learning. Pressey (1926) realized Thorndike's (1912) vision of a mechanical sequencer 50 years before the onset of the personal computer era, designing a typewriter-like device that presented a frame of text and recorded users' keystroke responses. These "teaching machines" were based on the same principle as simple contingency response boxes: the behaviorist premise that in order for instruction to be effective, learning needed to be student-paced, active, and errorless, and feedback on performance needed to be immediate and personalized (Skinner, 1968).

Skinner's (1968) theory of instruction is based on his ideas of operant conditioning (i.e., that human behavior is shaped by contingencies of reinforcement). If we want a behavior to become more probable, it needs to be reinforced. Thus, in programmed instruction, new and complex patterns of behavior are "learned" by conditioning the student or animal to generate the desired behavior or product, either through extensive coaching, explicit directions, or rewarding responses that approximate the correct response. After the target behavior is produced, supports are gradually removed and only wholly correct responses are reinforced (i.e., shaping or fading). An example of an application of this theory to a learning task offered by Skinner is a vocabulary lesson presented on a teaching machine. A student is taught to spell a new vocabulary word incrementally, first by copying the word, then by filling in a few missing letters, and finally by producing the whole word to fill in a blank in a sentence. Important to Skinner is that the student "has probably learned to spell the word without a mistake" (1968, p. 41). It is also important that the student actively generates their response. Skinner argues that composing an answer (putting letters or words in blanks) is superior to selecting an answer from a multiple-choice set of alternatives, as it not only teaches what it "means" to know that the word is right, but also that it reduces the likelihood that incorrect responses could be strengthened through association. The machine then gives them immediate feedback (the student is shown the correct answer and scores him- or herself). This "feedback" acts as reinforcement and strengthens correct responses and weakens the incorrect responses. Skinner argues that these methods are effective because students can pace themselves and always be busy and alert—whereas lectures and textbook reading can lead to boredom.

When one examines these features of the behaviorist approach to instruction, there are striking similarities to many current approaches in instructional technology. Today's CAI (computer-assisted instruction) systems are somewhat more advanced than their programmed predecessors in their ability to accept multiword responses instead of single letters, numbers, or words. They also can automatically score responses, instead of relying on the student to score themselves. New language analysis programs can also allow for some scoring of open-ended responses. However, these systems provide mostly feedback on answers from prestored sets of messages (explaining why answers are right or wrong in a generic manner). Thus, although these programs provide support to the learner, the feedback is not individualized to the student (Aleven, Stahl, Schworm, Fischer, & Wallace, 2003). Intelligent Tutoring Systems, on the other hand, represent a newer generation of supportive learning environments that utilize cognitive models to provide individualized instruction. This approach will be discussed in more detail later. At the turn of the millennium, however, few contemporary commercial software programs seek to tailor instruction using cognitive modeling, and behaviorist-inspired software technologies continue to dominate the landscape in schools.

THE COGNITIVE REVOLUTION

Behaviorist methods can be successful forms of instruction, but it is important to note the kinds of content that are likely to be successfully acquired with such an approach. The examples that Skinner gives for programmed instruction span such simple tasks as learning spelling, arithmetic, geographical facts, foreign language vocabulary, anatomical terms, and teaching a student to recite a poem. The simple response and feedback chains espoused in the behaviorist tradition are likely to be good ways to teach such simple associations like country names and their capitals, or even country names and their main geographical features. However, it is difficult to envision exactly how such an instructional approach could be used to teach students, for example, why particular geographical features are found in different places around the globe. In a number of places, Skinner refers to his approach as producing skilled behavior. A distinction needs to be made, however, between the learning of simple discriminations, associations, or procedural skills (e.g., vocabulary or arithmetic), and the understanding of complex concepts such as plate tectonics or photosynthesis.

Nevertheless, Skinner maintained that complex topics, such as high school physics, could be taught via fill-in-the-blank exercises. For example, consider a lesson on the emission of light. Fill-in-the-blank exercises are intended to enhance the students' ability to learn what technical vocabulary words fit in sentences of a physics text. In additional exercises, students then use the same terms to talk about familiar objects, such as flashlights and candles, that also emit light. Skinner claims that being able to discriminate when a term should be applied in a particular sentence represents an understanding of the topic. In essence, if students are capable of perceiving under what conditions they should generate a certain answer, they have "learned" what that term means, and not just how to use it in a sentence. What many researchers have questioned is whether the learning of isolated facts can effectively support the understanding of complex concepts. If an approach such as the one outlined above were effective, one could ask whether the learning occurs because of the reinforcement of correct vocabulary use, or whether the examples of everyday objects are critical to providing the student with prior knowledge or a mental model upon which to develop their understanding of the topic.

The notions that prior knowledge and mental representations might be necessary to explain learning were the foundations of many researchers' dissatisfaction with behaviorism, and a main premise behind the cognitive revolution. Even animal behavior researchers such as Tolman (1948) were forced to resort to the use of mental maps as an explanatory construct to explain how rats were able to run a maze correctly when placed at a new entry point. While behaviorism stressed errorless learning of associations, one can see the emergence of schema and mental model theories as conceptualizing learning as the process of constructing, assimilating, adapting, or revising a representation (cf. Alba & Hasher, 1983; Anderson, Reynolds, Schallert, & Goetz, 1977). With the cognitive revolution, the emphasis in instruction shifted from simple associations to helping the student integrate new information with prior knowledge, and prompting the student to elaborate on incoming information to build coherent and connected models of the subject matter (Bransford, Brown, & Cocking, 2000; Gardner, 1985).

From Information Transmission to Active Learning

The cognitive revolution has resulted in a view of knowledge acquisition that seeks to replace the *transmission* model, in which the role of education is to transmit a body of facts to students, with a *constructivist* model, in which the goal is for students to gain an understanding of the subject matter through their own exploration and problem solving. Constructivist approaches emphasize "learning by doing" and active manipulation of information in order to achieve problem-solving goals. They also require elaborate responses, often in the form of external models or authentic learning products. The technology in constructivist learning environments supports the construction of mental representations or models in multiple forms, which help students construct their own meaning from instances, data, or evidence. The use of multiple representations and generalization from concrete examples is also meant to strengthen the likelihood that this knowledge will transfer to new situations. Related to this is the movement toward the use of multiple representations of content in instruction (i.e., instead of memorizing a single verbal description or diagram, students are faced with multiple representations that they need to resolve in order to construct their own coherent understanding of subject matter). Constructivist-based technologies take many forms, but four basic implementations are intelligent tutoring systems, simulation or modeling environments, project- or problem-oriented learning environments, and participatory simulations. These approaches differ in the amount of curricular structure and tools that are offered to the student, and are often combined in specific programs. However, these implementations all share a common emphasis on the development of coherent mental representations of subject matter.

Intelligent Tutoring Systems

Current technology offers the possibility of customizing instruction for each student. In most classrooms, there is but one teacher in a room of 20 to 30 students. Yet, despite this disparity, the teacher is still responsible for several elements of instruction that can be critical to positive learning outcomes: matching students to materials and tasks, prompting and scaffolding the learning process, and giving feedback or assessments of learning outcomes. One way that instructional technology has sought to produce improvements in the classroom is by attempting to fill several of these teacher roles through dynamic, interactive systems that can support learning by structuring or responding to students as they work individually or in groups. Attempts have been made to optimize the match of the learner to the content or structure of a lesson, for instance by prior knowledge or ability assessments. (Some of these systems are more online and dynamic than others, using online tests, progress tracking, or LSA [latent semantic analysis] to derive the student's level of understanding before or during a lesson.) Other approaches rely on teacher or student self-reports of ability level, skills, or learning preferences to determine the version of a tutor or program that a student receives.

At the heart of the benefit of computerized tutoring environments is their ability to provide personalized support and feedback to a student based on their performance. The most successful tutoring environments use a cognitive model of the student to provide context and learner-sensitive feedback, as well as to tailor the curriculum to the student's individual learning needs. Using information gleaned from student responses, including errors and correctly solved problems, the intelligent tutoring system (ITS) can track student understanding in a cognitive model based on an analysis of the skills and procedures needed to perform well in the domain. Because of the reliance on cognitive models of student understanding, ITS learning environments have also been called "cognitive tutors" and have been shown to support learning better than simpler CAI systems (Anderson, Boyle, Corbett, & Lewis, 1990).

The Algebra Cognitive Tutor (ACT) is one example of a PC-based ITS (Koedinger, Anderson, Hadley, & Mark, 1997). Students work through an organized curriculum of problems by reading a text description of the situation and are posed a number of questions about it. The problems students are asked to investigate are real-life situations that require algebraic solutions like figuring out how to make money in a snow shoveling business. They investigate the situation by representing it graphically, in tabular form and in symbolic equations. They use these multiple representations to understand the problem and answer the questions.

Students use the tutor individually, and critical to its design is a cognitive model of student performance that it uses to track students' progress. The tutor is mostly silent, but when help is needed, the tutor can give hints appropriate for the student. Errors are flagged for the student to correct. For common errors, a message is provided explaining what is wrong with an answer. Immediate feedback is based on a particular student's understanding of each problem, and new problems are given based on analysis of weaknesses in the student's set of skills. Additionally, teachers are also supported in their use of this technology. A workbook has been created that accompanies the tutor to give teachers useful ideas for implementing the technology in the classroom. As a package, the Algebra Cognitive Tutor consistently yields learning gains over and above comparison classes who are taught algebra using a traditional curriculum (Koedinger et al., 1997). These gains are seen both on standardized assessments as well as on tests that directly address everyday problem-solving and representation skills.

Simulation Environments

Simulation learning environments allow students to explore multiple representations of content, so that information can be compared, contrasted, or integrated across different sources, configurations, or modalities. Technology is especially useful for visual displays and representations. Computers can easily offer access to animations and visualizations not available through 'traditional' classroom materials (e.g., textbooks), and in the latest VR (virtual reality) systems, learners can actually be immersed in the environment about which they are learning.

Even on its own, the ability to view visual representations seems to offer many affordances for learning (Wiley, 2003). Visualizations can be an effective means of analyzing complex streams of information, like weather patterns or stock market data. Similarly, visual displays may be quite effective for the comprehension of complex parallel systems like traffic patterns. Visual displays are also essential to virtual training environments, which seem to be most effective for content domains that require inherently perceptual or motor skills, like piloting or surgery. This potential for "virtual firsthand experience" through visualizations can not only enhance the saliency of relationships between materials, but can also allow for a larger knowledge base (i.e., verbal and spatial) to be applied to the learning process.

The ability to portray multiple representations can support the mapping of relations between knowledge units, for instance between concrete instances of observed data (like volcanic eruptions or selling prices of houses) and their representations in a graph or other symbolic data display. The available comparison of the two makes both the referents, and important relations between the elements in the system, more apparent, whereas this might not be the case if it were just summarized in a textbook chapter. Similarly, students could be presented with concrete and abstract versions of representations of the circulatory system, for example, which might facilitate the mapping process. Visual representations could also be "layered" in such a way that students can be prompted to see the correspondence between multiple representations at different grain sizes (i.e., the functioning of the circulatory system vs. the role of white blood cells in the blood stream vs. the cell biology of white blood cells). Finally, the classic pairing of text description and image can allow for readers to "see" a system that they are attempting to understand, while the text can make the dynamic relations between the elements of the system explicit.

Computer simulations based on the input of the user also allow students to see what variables may affect phenomena, view different perspectives, and test their own understanding of systems. Here, as in ITS learning environments, feedback is available directly to the student, as they can see what "works" and produces a desired outcome in their simulations. Simulation environments have been especially important for learning in the sciences where visualization is often a key to understanding (White, 1993) and can help students to make important distinctions in concepts such as heat and temperature (Linn, Songer, & Eylon, 1996). Some simulation environments employ an organized curriculum or problem set, while others are used more openly as exploration spaces.

Thinkertools is one example of a PC-based simulation environment (White & Schwartz, 1999), designed to enhance students' understanding of physics, and whose effectiveness has also been empirically demonstrated by improvements on year-end assessments. ThinkerTools approaches physics instruction from a fundamentally different perspective than "traditional" physics instruction. Rather than focusing on traditional, top-down quantitative instruction of formulas and applications, ThinkerTools approaches physics teaching with a focus on "constructing causal models" of understanding through the use of intermediary causal models (computer simulations) or microworlds (White, 1993, 1995; White & Schwartz, 1999).

In ThinkerTools, the units are not solely computer modeling exercises. In addition to instruction on how to run the simulations in the computer modeling program, each unit involves hands-on experimentation, guided inquiry, and hypothesis testing, as well as debate and interaction among individuals regarding the designated topic. To address individual differences in performance and prior knowledge, the teacher can customize the content and parameters of the computer experiments. Both students and teachers are provided with a resource book that provides a detailed road map through each unit.

The design of the ThinkerTools interface may also be important for the positive learning outcomes that have been found. Graphs are simple, as is the animation in the simulated experiments. There appear to be few irrelevant, extraneous "bells and whistles." Students are also involved in inputting data, and constructing the graphs and notes from their experiments, so the correspondence between the simulations and graphs is reinforced.

ThinkerTools represents the fusion of the traditional classroom with technology. Students conduct simulation experiments on the computer, the computer allows them to save their work, and further provides them the chance to test multiple hypotheses easily and quickly. Students then must apply their gained knowledge to subsequent "real-world" demonstrations. This integration of real-world experience and computer-aided instruction ensures that the information students are exposed to is connected to their existing knowledge, is supported through interaction with peers, fits the global goal of promoting scientific inquiry, and ultimately leads to an increase in students' understanding of physics (White & Schwartz, 1999).

Project-Based Learning Environments

Project-based learning environments generally employ more complex, realistic, and less-directive discovery spaces, inspired by situated learning approaches. One example of such an approach is the Jasper Woodbury Problem Solving Series (Cognitive and Technology Group at Vanderbilt, 1997) in which students are presented with 12 interactive video environments, and are challenged to solve problems that require the application of mathematical concepts (like designing a playground). Students work together to build models, compute measurements, and design solutions. These programs have demonstrated gains in student learning of mathematical concepts, as well as changes in communication skills and attitudes toward math. However, these experiences have also highlighted some of the attendant complexities of the introduction of such activities in the classroom. Perhaps most importantly, the lack of explicit structure and sequence in the learning activity forces a heavy reliance on the metacognitive ability and background knowledge of students. In recent years, researchers have begun to focus on the importance of embedding scaffolding or help systems as an integral component of learning applications (e.g., Aleven et al., 2003; Reiser et al., 2001).

Collaborative Simulations with Embedded Technology

The fourth approach within recent uses of technology may be best thought of as a hybrid between collaborative problem solving and simulation environments. One example of this new approach are participatory simulations (Resnick & Wilensky, 1998). Participatory simulations engage groups of learners in the enactment of a dynamic model, with students controlling model parameters, often by interacting with common physical devices embedded with computational capabilities. The critical design feature in this approach is that students take part in collaborative activities, the result of which is an emergent representation of the phenomena they are trying to understand. A more specific example of this approach is Geney, a collaborative problem-solving application to help children explore genetic concepts using multiple wireless PDAs and a central personal computer (Danesh, Inkpen, Lau, Shu, & Booth, 2001). Here, the application is used to implement a game played by the entire class, in order to teach basic genetic concepts of dominant and recessive genes. Each PDA is shared by a pair of students, but each member has their own stylus for input. In this game, each PDA represents a pond of fish. Within each pond, fish age and die. What students can do is exchange fish with other pairs through their infrared ports, and then mate their fish and observe the characteristics of the offspring. (A limited set of traits is used to reduce complexity.) The goal of the game is for the students to produce a fish with a particular set of characteristics. To do so, the class must work cooperatively, gathering genetic material from multiple ponds. Each pond only represents a portion of the gene pool. However, students can upload their information to a central PC to see the complete family tree of fish. The collaborative activity seems to be very engaging and exciting. Even quieter children who were usually less inclined to work with others were brought into discussions. This use of technology seems promising, but research on it is still in its early stages, and learning outcomes have yet to be examined.

In a pilot experiment of our own using an analogous kind of activity (Moher et al., 2003), we have investigated how collaboration with handhelds can support the acquisition of scientific reasoning strategies. Similar to the Geney application, students must engage in cooperative problem solving in order to turn a field of circles on a large plasma screen all one color. Each student has a wireless PDA that controls a single dot. In other words, the students act as the variables in this experiment. Successful attainment of the goal requires that the class, as a whole, recognizes that in order to achieve a desired pattern only one person can click their PDA at a time. In other words, students must adopt a strategy of manipulating only one variable at a time (a control of variables strategy) in order to successfully complete the exercise. We found that after a class of third-grade students engaged in this activity, the majority of them were able to generalize the control of variables strategy to a new transfer problem (determining which dog food makes dogs sick). Performance of individuals on the transfer problem showed a significant advance versus a similar pretest question, as well as in relation to normative levels of understanding of this concept reported in the literature for this age group. These data suggest that collaborative problem solving or simulation activities are a promising use of handheld and other mobile computing technologies, and may be an important future direction for educational technology research.

Although the above examples utilize technology in very different ways, these approaches also share a number of common elements, as do many examples in this generation of instructional technology. A number of learning environments or contexts that have produced positive learning gains use inquiry/problem-solving tasks to help focus students on important concepts during their exploration. Providing students with a specific inquiry task to guide their activity, like "What caused the eruption of Mt. St. Helens?" or "Why are all the California tree frogs dying?" seems to be important for keeping students on task and working constructively (Wiley & Voss, 1999). Such problem-solving tasks can also help to "anchor" cognition in a realistic, meaningful learning activity.

Many current examples of instructional technology also involve learning by active manipulation of data. This often involves the use of multiple representations and viewing data from different perspectives, or in different forms. All these examples also have a method of feedback to the student. The feedback in the ACT is most tailored, but the feedback that students receive from seeing their simulations in ThinkerTools, and the results of their collaborations on a larger screen in the activities using handhelds, also seem important to the learning process. Many examples of current instructional technology also involve some sort of hands-on manipulation or activity interweaved with the technology. In most cases, the benefits of both the hands-on or exploratory activities, and the technology-supported activities, will be most beneficial when they are reflected upon or integrated conceptually through discussions. And, it is important to note that both ACT and Thinker Tools provided support to teachers so they could accomplish this integration of technology into the classroom discourse. This leads to another set of common elements that cross many current learning contexts: the use of collaboration, discussion, and/or debate in the learning process. The social processes of learning, and the role that technology can play in supporting collaborative learning, is receiving more and more attention in educational research, and is an important part of many learning environments.

TRENDS IN INSTRUCTIONAL TECHNOLOGY

The above examples illustrate several trends that seem to have emerged in educational research in the past decade. The first trend we note is from individual to group learning contexts. The second is from an emphasis on cognitive activity to a recognition of the role of metacognitive activity in the learning process. The third trend we note is a movement from creating learning activities to fit around technology, to a movement toward embedding technology into meaningful learning activities.

From Individual to Collaborative Learning Contexts

As a number of other authors in this volume have remarked, the role of social processes in learning has received increasing attention in the past few years. Emphasis within the cognitive psychology tradition has been overwhelmingly focused on individuals acting and learning alone. This can be an excellent approach to effective instruction, especially in the paragon case of the Algebra Cognitive Tutor, which gains much of its power from the detailed analysis of the cognitive skills needed for an individual to understand the domain. If this method could be followed for all content areas it would clearly lead to powerful learning gains. However, since all subject matters are not as easily reduced to a set of production rules, we must investigate other effective forms of instruction. One promising area is the examination of learning that occurs through social interaction.

While the original reasons for having small groups of children share a computer may have been pragmatic (due to scarce resources), there are reasons to believe that collaboration may be important for positive learning outcomes (Webb & Palincsar, 1996). Collaboration is essential for real

scientific inquiry, which happens in laboratories and among communities of researchers on a regular basis in the real world. Although there have been numerous findings that groups do not outperform individuals in the social psychology literature, a few studies have found learning benefits versus individual controls (Barron, 2000, 2003; O'Donnell & Dansereau, 1993; O'Donnell, Dansereau, Hall, & Skaggs, 1990). The recent work of Anderson and his colleagues has also demonstrated that peer interaction may be a critical mechanism for the development of reasoning skills among schoolchildren (Anderson et al., 2001).

Many new technologies have become available to support collaboration, which may be responsible for this growing trend and interest in collaboration as an effective means of instruction. Although collaborative learning seems to be an important new direction for research, any new technology needs to be investigated, specifically in terms of how it can support collaborative interaction and when such interaction actually results in better learning, as results are still decidedly mixed on this topic.

From Cognitive to Metacognitive

Intuitively, many educational researchers believe that collaboration can benefit learning because students can provide each other with prompts for reflection and explanation, contribute multiple sources of knowledge, and explicitly generate more planning and monitoring statements of goals. All of these are elements of successful metacognitive activity, and collaboration may be especially important for supporting metacognitive skills and awareness. In addition, the role of supports and prompts for metacognition as students are engaged in learning activities is an important direction for future research in interactive learning environments.

Technology has enabled new possibilities in terms of placing students in rich multimedia problem spaces or virtual environments that allows for learning questions to be posed in such a way that they "feel" more authentic and situated to the learner. Also, the lack of explicit curricular structure and sequence in some learning environments may allow for the excitement of "discovery" or "exploration." This freedom to explore and discover, however, is a double-edged sword. While enthusiasm and interest may be enhanced by the discovery process, discovery may only work with students who have adequate metacognitive ability and background knowledge. Appropriate scaffolds are necessary for students who might be deficient in these areas, and are realizable through technology. In recent years, researchers have begun to focus on the importance of individualizing scaffolding or help systems as an integral component of learning applications (e.g., Aleven et al., 2003; Reiser et al., 2001).

From Technology-in-a-Box to Immersive Technology

The vast majority of new technologies were not developed specifically for education. Most of our current educational technologies have been developed by asking the question "How can we use this tool for education?", and then adapting existing resources to the educational task at hand. The tool exists first and instruction is fitted around it. This leads to many awkward, less than ideal situations. As a prime example, desktop computing is a problematic fit for school classrooms, especially elementary school classrooms where children would rather be moving around the room. Even among older children, there is often a mismatch between the number of available computers and the number of students. When a mismatch occurs between resources and students, the teacher is forced to establish a scheduling regimen around the scarce resource (further burdening teachers, rather than assisting them). For example, in a classroom with one microscope, if each of 28 kids gets 15 minutes at the scope to observe and record their observations, the teacher must plan a full day's worth of "parallel" activities—activities that won't be impacted by the comings and goings of kids to and from the microscope—for the rest of the class to do while waiting for their turn for the microscope. In a classroom with one computer, certain activities, such as the use of the Internet as a resource for open-ended research questions, becomes almost impossible to coordinate. At the elementary school level in particular, the physical needs and abilities of younger children are not well suited to extended interaction with desktop computers. Over the past several years, motivated by the active and collaborative learning exigencies outlined above, researchers have begun to explore alternative means for students to interact with computers and each other in meaningful learning activities.

One approach to dealing with these problems has been, essentially, the miniaturization of the computer. Palm- and tablet-size computers provide a less expensive and considerably more portable platform that can be utilized at the physical point of phenomena. Highly portable computing devices are being used to support students' collection of environmental probe data in the real world (e.g., the BioKids project; Parr, Jones, & Songer, 2002) as well as in simulated settings in the classroom (Moher, Johnson, Cho, & Lin, 2000). Handhelds are also being used for activities such as personal reflection and planning (Soloway et al., 1999).

A complementary approach has been the enlargement of the display. As screen technologies improve and prices drop, larger tubes, panels, and projectors, capable of supporting small-group as well as whole-class activities, have begun to fall within the price points of schools. A new class of applications called single display groupware has begun to emerge (Druin, 2002; Inkpen, 2000), combining multiple private-user affordances with a large common display for collaboration.

New computing devices and embedded technologies are being developed and implemented in participatory simulations. An interesting example is Thinking Tags (Colella, Borovoy, & Resnick, 1998), small necklaces with digital and LED displays that sense the presence of proximate tags and exchange information, which have been used by groups of students for simulating disease vectors and inheritance of genes. Wilensky and Stroup's HubNet (1999) architecture allows students to network their local devices (computers or calculators), and project the simulation onto a large common display. This provides students with a view of the aggregate state of the simulation, which may be critical for reflection and understanding. Finally, new technologies have been developed that allow for the creation of virtual worlds. A completely different sense of "immersion" arises from the use of technologies intended to situate users within virtual reality environments—in the depths of Washington's Puget Sound (Windschitl & Winn, 2000) or riding along on an electron (Dede, Salzman, Loftin, & Ash, 2000).

With all these changes and developments in technologies and their affordances, at present, we are still largely engaged in the arduous process of adapting business technologies to schools. The one-person, one-keyboard, one-screen physical configuration of computer systems is well suited to the deskbound, continuous-access world of the office worker, but does not translate easily to schools where there is a great deal more physical movement, and where the availability of computers is brief, infrequent, and synchronized to a daily schedule. We need to ensure that sufficient, appropriate resources are accessible to teachers that will allow them to use available technologies to an optimal level. At the same time, we need to explore emerging technologies that can more economically overcome the "availability gap" and support effective learning. New handheld and embedded-chip technologies that enable mobile and active learning seem quite promising in this regard.

THE FINAL WORD: REASONS FOR PESSIMISM AND OPTIMISM

Although there might still exist some important questions regarding the educational effectiveness of the latest technological learning environments, there are several reasons for continued optimism about educational uses of technology. Technology continues to provide new and motivating learning contexts for students. Technology is becoming more available and students are increasingly comfortable with technology. Finally, perhaps the most promising reason on the horizon, is that new technologies are emerging that will allow for teachers to bring technology into the classroom without having to mold course planning around the computer. This being said, empirical demonstrations of how and when educational technologies actually result in positive learning outcomes are sorely needed. Technology, when based in cognitive models of student learning, and used appropriately, can raise the level of performance. However, it is clear that simply introducing technological gadgets into the classroom will not improve learning. The lesson as we moved from behaviorist to cognitive principles of instruction was that it was important to consider and support the learner's mental model of the subject matter. Current educational technologies that focus students' attention on important concepts—either through structured instruction, prompts and feedback, through simulations, or through authentic problem solving—have produced positive learning gains. Recent trends suggest that the next movement in educational technology is considering the learning activity in terms of its social context, supporting activity and interaction among students, and perhaps even discovering new kinds of learning activities.

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CHAPTER 10

TRANSFER AND PROBLEM SOLVING

A Psychological Integration of Models, Metaphors, and Methods

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ABSTRACT

The following three themes are the storyline around which this chapter is developed. The first theme is the identification of a philosophy of science that guides the study of adaptive human behavior where human learning is a primary agent of change, and transfer and problem solving are but special cases. The second theme is a selective historical review of transfer and problem-solving research in the United States that identifies: (1) major theoretical models and metaphors and (2) the methods and materials used to test respective theories. This chronology includes (1) initial efforts (circa 1900–1920), (2) verbal learning research (circa 1920–1970), and (3) the cognitive revolution (circa 1970–present). The third theme is a subtheme that involves identifying similarities and differences in the study of transfer and problem solving between 1900 and 1970. This subtheme is carried over into

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