Cognition and Distance Learning

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Can distance learning transform higher education, saving money and improving student learning? Modern technologies allow instructors to design distance learning environments with all the features of traditional courses and more. What findings from research on instruction can help course designers make effective choices? I argue that students who take an autonomous stance towards instruction tend to learn from most courses, and that course designers who take a scaffolded knowledge integration approach to course design can enable autonomous learning. To help designers create courses that transform passive students into autonomous learners, this article draws on recent research on instruction. I describe the scaffolded knowledge integration framework and use this framework to interpret current approaches to distance learning.

Many believe that electronic distance education can transform higher education, saving money and improving learning outcomes (e.g., Hiltz, 1994; Holmberg, 1995; Lockwood, 1995). To understand these claims and their implications, this article examines the stance towards instruction taken by course designers and the stance towards learning taken by students. I argue that students who take an *autonomous* stance towards learning succeed in most courses, and that course designers who take a *scaffolded knowledge integration* stance toward instruction succeed with most learners. Limited learning occurs when students take a passive stance towards learning and designers take a transmission stance towards instruction. To guide designers of distance learning environments, I distinguish passive, active, and autonomous learners, as well as transmission, hands-on, and scaffolded instruction. I discuss how scaffolded instruction can motivate students to become autonomous learners. Several electronic learning environments, as well as the scaffolded knowledge integration framework developed from previous instructional research, illustrate effective practices (Linn, 1995; Linn, diSessa, Pea, & Songer, 1994). I close with some specific directions for design of effective distance learning environments.

Autonomous learners take the initiative to learn what they need to know in courses and also continue to improve their understanding as they re-encounter course topics in their lives. Autonomous learners critique their own understanding, recognize when they need help, and seek opportunities to assess their comprehension by applying what they have learned in novel situations. Many students resist autonomous learning, complaining that they have no idea what they should learn, insufficient time to create their own learning opportunities, and no sense of whether they have understood something. Often, course instructors reinforce this resistance by discouraging students from tailoring courses to their own needs or failing to provide opportunities to develop the cognitive skills necessary for autonomous learning. Electronic distance education courses generally require more autonomous learning ability than more traditional courses because there is less interaction between course participants. And, the most cost-effective aspects of electronic distance education, such as video-lectures or electronic questions and answers, are poorly suited to helping students develop autonomous learning ability.

How can electronic distance course designers create learning environments that support learners so they can become autonomous? What are some of the features of autonomous learners that course designers need to encourage? First, autonomous learners take responsibility for their own learning. They determine what to study, decide how to allocate their time, and select activities that will achieve their goals. Autonomous learners assess *their own* learning, diagnose weaknesses, seek help, work on topics they do not understand, and allocate study time to the most important aspects of the course. Second, autonomous learners know their own learning habits. They know when to memorize, when to review, and when to discuss material with a classmate or instructor. Third, autonomous learners set realistic goals and adjust their goals in light of feedback. Autonomous learners use past experience to determine the effort needed to learn new material, write a report, or design a problem solution. Autonomous learners generally earn the grades they expect because they understand the relationship between their actions and their performance.

This article analyzes how designers of electronic distance learning environments can help students become autonomous learners of their course topic. Students come to most courses lacking autonomous learning skill in the course topic. They often gain these skills from course features that are minimized in distance courses, such as contrasting alternative problem solutions, analyzing personal mistakes, participating in informal student discussion, or receiving mentoring from advanced students. In addition, students vary in their understanding of their own learning habits. Ideally, instructors will also help students make progress in understanding their own learning, but this discussion focuses on distance environments that help students become autonomous learners of the discipline.

Today's technologies allow instructors to design distance learning courses that employ all the methods used in traditional classrooms and more. Instructors can lecture, respond to questions, ask students to answer questions, assign computer laboratory work, require practical work, supervise projects, or conduct small group discussions at a distance with electronic technologies. Special opportunities with electronic technologies such as simulations, networked communication, and World Wide Web resources have the potential of making instruction better. Such technologies might make instruction more efficient because students learn more material in a course, or because course delivery costs less. They may help students apply what they learn more widely, or prepare students to draw on electronic resources to add to their understanding when the need arises. Such technologies may encourage autonomy by performing some tasks for the learner, such as computation in the case of symbolic algebra programs or drafting in the case of computer assisted design programs, thereby freeing the student to analyze problem solutions. These technologies support "just in time" learning, allowing instructors to provide a firm foundation and prepare students to develop their understanding as the need arises.

Autonomous learners use books, electronic media, networked communication, even computer manuals to gain a linked, connected, integrated and cohesive understanding of a topic. This understanding enables them to critique new information, solve novel problems, or carry out a research program. As educators, we face the challenge of creating motivated and autonomous learners, and providing them with a firm foundation for lifelong learning. How can electronic distance learning environments help create autonomous lifelong learners?

Courses can help learners recognize the benefits of their learning by ensuring that students encounter personally relevant problems. Courses can help learners identify personal, moral, workplace, or societal benefits of their learning. When learners have a personal goal of understanding, integrating, and reusing the material they encounter, they guide their own learning. Autonomous students may use courses to achieve goals that differ from those of the instructors. For example, one distance education student remarked, "I took this course to learn how to solve a certain problem in advanced physics. When I learned that, I stopped sending in lessons" (James & Wedemeyer, 1960, p. 93).

How can distance learning environments teach autonomous learning? Reflect on how you as a reader learn from print material such as this article. Do you ask yourself questions, argue with the author, or skim the headings before delving into the details? What do you do when you encounter "difficult" ideas? Do you review, abandon the material, persevere in hopes of clarification, or just keep going until you reach the end? These are all decisions that require autonomous learning ability, but instructors can help students make effective decisions.

To learn to create new ideas and solve novel problems throughout their lives, learners must recognize *when, how,* and *why* they learn new material. How can distance learning environments help students select activities compatible with their goals and develop autonomous learning abilities? Helping students diagnose personal goals, strengths, and limitations generally requires personalized guidance and opportunities to tailor course activities to personal goals in independent projects. The ideal distance learning environment combines electronic and human resources to create autonomous, lifelong learners. For autonomous learners to take responsibility for their own learning, they need to know enough about the discipline to set realistic goals, monitor progress, reflect on understanding, reconsider ideas, and seek guidance from peers as well as teachers. And, they need activities that permit them to practice these skills.

Active, Passive, and Autonomous Learning

It is useful to distinguish passive, active, and autonomous learning. To take an *autonomous* stance towards a discipline requires a sense of appropriate goals and indicators of success. For example, learners encountering computer programming courses for the first time have difficulty determining whether they should memorize commands, study problem solutions, identify abstract patterns, or critique solutions written by others (Linn & Clancy, 1992a). Some courses transform a disposition toward autonomous learning into effective autonomous activity, but others do not. The scaffolded knowledge integration framework, discussed below, has synthesized course features that contribute to autonomous learning.

To take a *passive* stance toward a discipline means leaving responsibility for selecting course goals and activities to the course designer. Passive learners expect to absorb information, often fail to identify connections between ideas, and frequently forget what they learn. For example, programming students who fail to distinguish between definitions and functions, or concentrate on memorizing details rather than concepts, may be taking a passive stance toward the material (Davis, Linn, & Clancy, 1995). Passive learners eschew reflection and may recall only the information they regularly re-encounter.

Active learners respond to hints and guidance, reflect when prompted, and follow course instructions, but do not internalize their activities. They rely on others to guide and monitor their learning. A broad range of instructional and learning research demonstrates the benefits of active learning (Anderson, Boyle, & Reiser, 1985; Anderson, Corbett, & Reiser, 1987; Bruner, 1966; Dewey, 1901; Piaget, 1952; Vygotsky, 1962, 1978, 1987). Yet, active learners need guidance to become autonomous, responsible learners. For example, computer science students frequently remark that they have learned the material they were taught and cannot understand why they performed poorly on an examination. Such responses suggest that students have not connected novel problems on exams to problems they previously solved, or failed to test conjectures, or lack abstract reusable patterns. In contrast, students who autonomously monitor their own progress may report that examination problems closely resemble problems from exercises (Linn & Clancy, 1992b). Scaffolded instruction can convert active learners into autonomous learners who develop a cohesive, linked, abstract understanding of a discipline, and monitor their own progress (Brown, 1978; Eylon & Linn, 1988; Flavell, 1976; Scardamalia & Bereiter, 1991).

Courses that convert active learners into autonomous learners help students take responsibility for their own learning by communicating what constitutes progress in a field, prompting for connections among examples, and encouraging critiques of the work of others. Courses that emphasize only correct problem solutions—rather than all the things that can go wrong in problem solving, or all the alternative interpretations that might plausibly arise—constrain active learners. In programming courses, when active learners are exposed to correct solutions they learn to use these solutions, but cannot distinguish correct and incorrect solutions in a multiple choice setting (Davis, Linn, Mann, & Clancy, 1993). Clancy and Linn (1992b) designed programming case studies to help students learn how to distinguish and synthesize solutions. Case studies illustrate the floundering and comparison of alternatives that precede a problem solution, and they engage students in abstracting reusable patterns. Self-paced courses using these case studies succeed in helping students become autonomous (Clancy & Linn, 1992a).

When designers create discovery activities, or open-ended, hands-on learning activities or project activities, they make learners active but not autonomous. Indeed, in many discovery environments, only students who figure out how to learn autonomously on their own will succeed. Programming environments lend themselves to discovery activities. Many current computer scientists learned programming languages on their own, or with minimal guidance, but many more gave up. Self-taught programmers use quite diverse strategies for solving problems (see Linn, Katz, Clancy, & Recker, 1992). Accounts of student success frequently emphasize the creativity, ingenuity, and resourcefulness of a few students. Instructional designers cite exciting breakthroughs made by students as evidence for the benefit of active learning (Lawler, 1985; Papert, 1968; Perkins, Schwartz, West, & Wiske, 1995). However, many more students need additional guidance to succeed.

For example, in LOGO environments, students participate in a brief introduction and then explore according to their interests (Papert, 1968; Turkle, 1984). Students might autonomously carry out creative projects or mindlessly repeat a few commands (Watt & Watt, 1986). Success stories abound (e.g., Lawler, du Boulay, Hughes, & Macleod, 1986), but more students succeed when instructors augment discovery environments by teaching students to become autonomous in individual and small group tutoring sessions (e.g., Dalbey & Linn, 1984). To behave autonomously by guiding their own investigations and monitoring their progress, most students need scaffolding that these environments leave to the instructor.

Instructional design often emphasizes what to transmit or opportunities to be active, rather than helping students become autonomous learners. Instead, to design for autonomous learning, instructors need to concentrate on how learners will build on and develop their ideas in this course and throughout their lives. Usually this succeeds best when students carry out larger and larger projects, in an environment that provides appropriate support. Today learners must deal with massive increases in world knowledge, regular career changes, and dizzying advances in technology (Jacobson, 1994). Responsible course designers must set learners on a path towards autonomy while at the same time making visible to students the thinking that autonomous learners use.

Transmission, Hands-on, or Scaffolded Instruction

Designers who take a *transmission* stance towards instruction, select and communicate the knowledge deemed appropriate for learners via lectures, text, video, and multimedia. Ironically, a few autonomous learners in any class can lull instructors into believing that this approach works. Only by analyzing the reasons that learners fail can designers appreciate the power of alternative approaches. When *hands-on* learning opportunities augment transmission courses, more students succeed (e.g., Linn, 1985; Shulman & Tamir, 1973). Instruction that *scaffolds* learners to carry out projects has even greater success (Collins, Brown, & Holum, 1991; Collins, Brown, & Newman, 1989; Linn & Clark, 1995). In a series of research studies of programming, science, and other disciplines, I have developed the scaffolded knowledge integration framework to help designers create courses that foster autonomy (Linn, 1995).

Scaffolded knowledge integration is based on a model of conceptual change that involves first *expanding* the repertoire of ideas held by the learner and then encouraging students to *distinguish* among these ideas by (a) *reflecting* on the nature of these ideas, and (b) *linking, connecting, and organizing* all ideas into a coherent, cohesive perspective. Many courses expand the repertoire of ideas but fail to support most students as they distinguish and reorganize their ideas. As a result, students forget what they learn, select ideas using superficial criteria, and report that what they learn is irrelevant to their lives.

Evidence that students fail to see connections between school and life is widespread. For example, in science at the beginning of eighth grade, 85% of students report that they have never learned anything they can use in their science courses (Linn & Songer, 1993). As students take more specialized courses, national assessments show that interest in science and other topics steadily wanes during the middle and high school years (NAEP, 1988).

Why foster autonomy rather than providing courses that serve autonomous learners? Some students in any course learn autonomously from transmission, or hands-on instruction, either because they already have the discipline-specific skills needed to distinguish ideas, or because they seek to learn these skills from instructors, experienced friends, or family members. Courses that serve only these autonomous learners can squander resources by causing unnecessary failures and increasing the need for remedial instruction. Yet, many blame students for failing courses rather than analyzing why failure occurs. If students fail because they lack informal networks of helpful peers or because they need disciplinary knowledge necessary for monitoring their own progress, or because they need criteria to distinguish alternative solutions, course redesign can increase success and save education dollars.

Scaffolded Knowledge Integration

Ten years of research on learning science, including computer science, suggests some guidelines for making distance learning effective.

- First, courses need goals that students can achieve.
- Second, courses need to make the important and difficult ideas, practices, and culture of the discipline visible to students.
- Third, students need opportunities to engage in autonomous learning strategies such as linking ideas, comparing alternatives, reflecting on progress, or critiquing ideas with guidance and support.
- Fourth, courses need to take advantage of the social nature of learning to illustrate alternative accounts of complex events, to engage communities in supporting each other as they learn, and to establish collaborative practices necessary for dealing with compelling, complex problems learners will face in their lives.

These issues are illustrated in the following section, with implications for distance learning research.

New Goals

Many courses reinforce a passive, memorization approach by selecting goals that students cannot connect to their existing ideas. In many physical science courses, for example, students conclude that objects remain in motion at school but came to rest at home, that light dies out at the movies but goes forever in science class, or that heat and temperature are interchangeable in everyday discourse but distinct in physics (Eylon & Linn, 1988). Students need bridging analogies and scientific models so they can distinguish ideas to make the links between school and home experience explicit. Successful courses often build on intermediate models that students can distinguish from their own ideas (Linn et al., 1994; White & Frederiksen, 1990), or help students find bridging analogies or linking concepts to connect their various experiences (Clement, Brown, & Zietsman, 1989; diSessa & Minstrell, in press).

For example, in thermodynamics students might learn a heat flow model before a molecular-kinetic model. The Computer as Learning Partner research (Linn, Songer, Lewis, & Stern, 1993) found that when students learned about molecular kinetic theory in science class, they could not connect their ideas to insulation, conduction, wilderness survival, keeping their lunch cold, and other personally relevant aspects of thermal phenomena. A heat-flow model of thermal events provided an excellent bridge for students to link their everyday and school ideas, and research shows it provides a firm foundation for subsequent learning of molecular kinetic theory.

Although selecting accessible goals sounds like common sense, several factors stand in the way. First, experts may set goals for introductory courses based on what they would like students who specialize in the discipline to know, rather than on what can realistically be learned (Linn, Songer, & Eylon, in press). Even the most talented students switch majors when courses have inaccessible goals (Seymour & Hewitt, 1994). Second, designers may blame poor teaching, rather than redesigning goals when teachers say students cannot connect course goals to their own ideas and personally relevant problems (Welch, 1979). Third, designers may lack alternative goals and need to conduct research to identify new goals that connect to student ideas, apply to personally relevant problems, and provide a firm foundation for more advanced courses. The design of distance learning environments affords an opportunity to reconsider course goals and make them accessible.

Making Thinking Visible

To teach accessible goals, the scaffolded knowledge integration research emphasizes a balance between making thinking visible (Collins et al., 1991) and encouraging autonomy (Linn, 1995). Many successful courses guide students to link ideas (Clement et al., 1989; diSessa, 1993; Linn et al., 1994). Linking promising ideas helps students select ideas that apply widely. Typically, students add new ideas and also retain existing ideas. To help students select new ideas when appropriate, students need to understand the new ideas and to distinguish old and new ideas using appropriate criteria.

For example, in the Computer as Learning Partner research, students add the heat-flow model to their repertoire of ideas and distinguish it from their intuitive view that heat and temperature are the same thing. To make heat flow visible, students use two simulation environments. In addition, the software guides students to predict how heat might flow and encourages students to carry out experiments to test their predictions. In one set of experiments they test metals, plastic, wool, and other materials for keeping a drink cold. As students carry out these experiments, they also respond to prompts that ask them to reflect about the meaning of their work. For example, the screen display in Figure 1 shows students reconciling the predictions that they have made for an experiment with the outcomes of the experiment and writing an explanation to link these two phenomena. Opportunities to reflect, encouraged by prompts such as the one in Figure 1, help students distinguish their ideas.

Students initially predict that aluminum foil will be best for keeping things cold because metals feel cold. After experimenting, some remark, "Styrofoam keeps hot things hot and cold things cold, it may be better than metal for keeping a drink cold." Overall, close to 90% of students distinguish their ideas about how metals feel from their beliefs about good insulators while participating in this course (Lewis & Linn, 1994).

To make thinking visible, scaffolded instructional design helps learners distinguish initial and course-taught ideas. Prompts and opportunities to reflect help students learn to monitor their own progress. By making thinking visible, courses also illustrate the nature of the discipline, the criteria that reasoners use to make decisions, and the methodologies that are appropriate for gathering evidence. As a result, learners gain insight into the strengths and limitations of problem solving processes, and also insights into the nature of progress in the discipline. These skills prepare learners to take responsibility for their own learning as their experience in the discipline develops. Distance learning environments have a special opportunity to identify technologies such as simulations that help students visualize complex ideas.

Encouraging Autonomy

Effective teachers guide students to take responsibility for their own learning. Families, mentorship programs, tutoring, and other educational approaches emphasize one-on-one or small group guidance to help students become autonomous learners in a given discipline. Tutoring yields gains of two standard deviation units in learning outcomes (Bloom, 1984).

Effective tutoring, like instruction, requires understanding of how students learn a topic and opportunities for students to engage in sustained investigations. Over the 10 years that the Computer as Learning Partner Project has operated in eighth grade, the teacher of the class has gained comprehensive insights into student difficulties with the subject matter and developed a set of prompts and questions that help students distinguish their ideas and organize their knowledge more effectively. The software designed for the Computer as Learning Partner Project has incorporated hints and prompts that can be diagnosed from student responses. In addition, careful analysis of the kinds of questions that students ask in class was used to design software tools to respond to routine or straightforward questions, such as, "What should I do next?" and "How do I do it?" As a result, software has enabled students to work independently and the teacher to spend time tutoring students with more complex difficulties. For class projects, electronic tutoring and computer coaching have also been successful when based on careful analysis of student progress (Linn & Clark, 1995). In distance education, such in-depth analysis of learning is especially important since student-teacher interaction may occur less regularly. Instructors might set up teleconferences, ensure frequent feedback on course homework, set up online discussions, and add other opportunities for one-on-one guidance, as well as ask students to describe their own processes of reflection and self-monitoring.

Capitalizing on the Social Nature of Learning

The final aspect of scaffolded knowledge integration involves taking advantage of contributions from students and teachers as they learn together. As problems in all disciplines increase in complexity, learners need more and more to work collaboratively. Simon (1981) described collaborative or group learning as a way to overcome "bounded rationality" and learn from others. Considerable research shows that peer interactions where students specialize in aspects of the curriculum and teach their peers benefit both the specialist and the novices (Brown & Campione, 1990; Palincsar & Brown, 1984; Pea & Gomez, 1992). Peer interactions can capture some of the power of teacher tutoring. For example, the reciprocal teaching research of Palincsar and Brown (Brown & Palincsar, 1987; Palincsar & Brown, 1984) demonstrates that with effective modeling, students can guide their peers to make sense of text descriptions of complex ideas. Students also benefit when peers answer their questions (Webb, 1989). In addition, groups of students can jointly contribute ideas and come up with

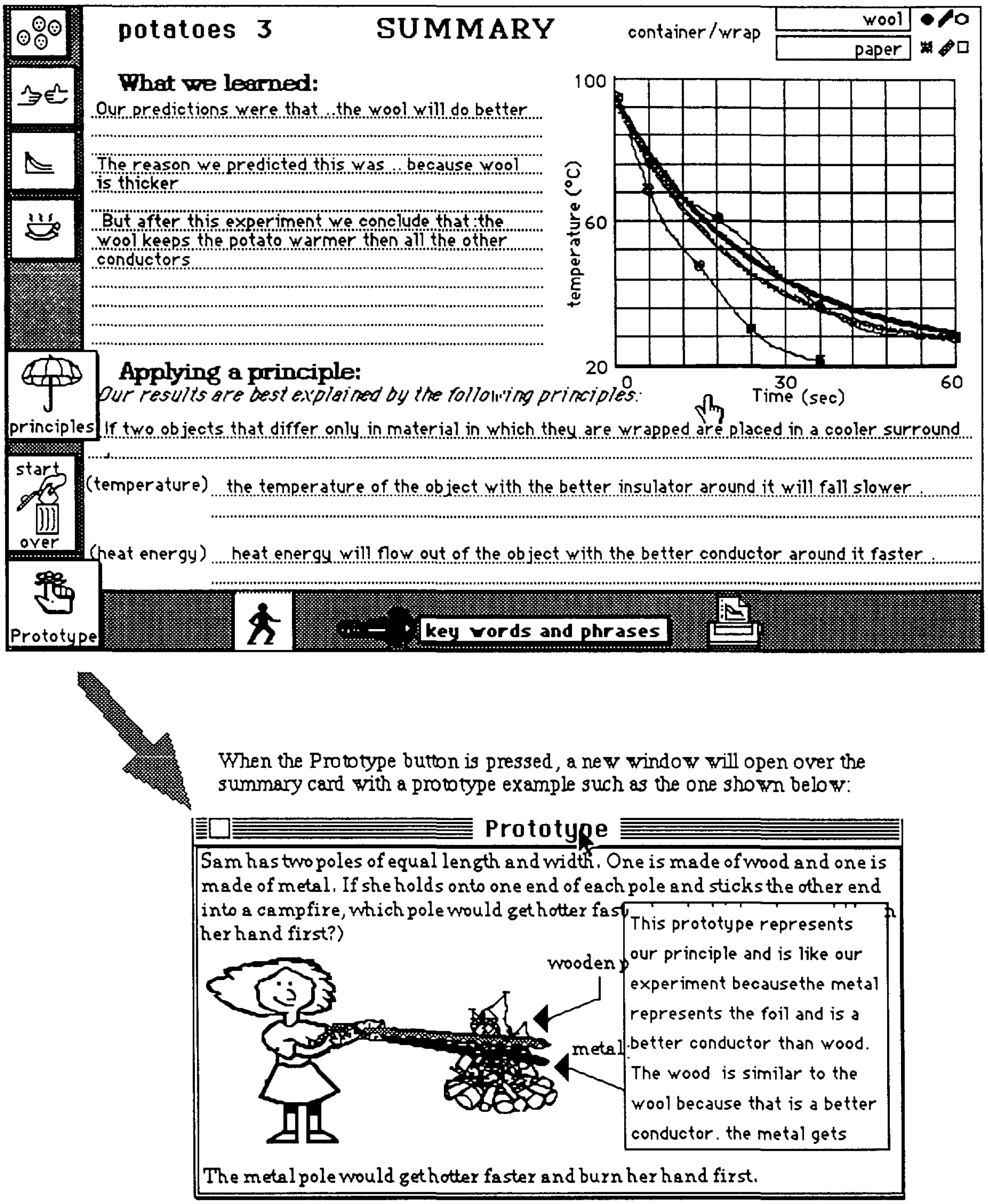

FIG. 1. The Computer as Learning Partner software prompts for reflection and knowledge integration.

effective insights into problem solutions. The Computer as Learning Partner Project, as well as the Knowledge Integration Environment Project, have created technological tools to support group learning and help individuals jointly contribute to each other's understanding (Bell, Davis, & Linn, 1995; Linn, 1996).

For example, the Multimedia Forum Kiosk (shown in Fig. 2) encourages students to contribute ideas to explain scientific phenomena presented using multimedia and to reflect on ideas of others (Hsi & Hoadley, 1994). Students respond to the multimedia stimulus, as well as to each other's comments. The Multimedia Forum Kiosk structures the discussion, helping students clarify how their comments contribute to the group discussion.

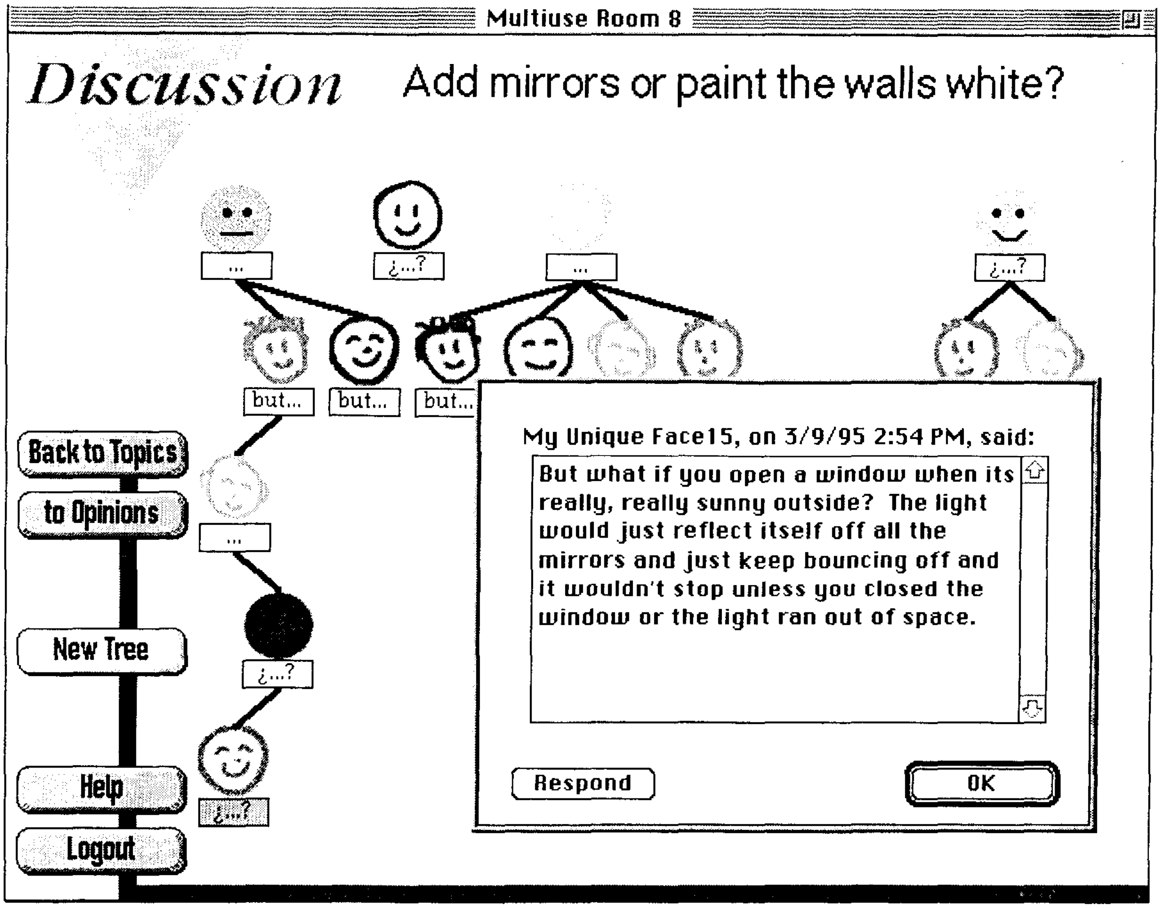

FIG. 2. The Multimedia Forum Kiosk allows anonymous and attributed comments in an electronic discussion.

Compared to classroom discussion or e-mail discussion, structured discussions help students generate alternatives and recognize views held by others. The Multimedia Forum Kiosk helps students recognize that many alternative explanations could account for data, and also models for students the process of analyzing information and evidence characteristic of scientific endeavor.

Often group discussion reinforces social norms and silences non-traditional students. Female students in engineering courses often report feeling silenced or excluded when working in groups (Agogino & Linn, 1992). Similarly, science students often reinforce the stereotype that females lack science ability. Efforts to take advantage of the social nature of science need to ensure that students interact in an atmosphere of mutual respect. Electronic, structured discussion helps to establish norms of respect. In Multimedia Forum Kiosk discussions, for example, females contribute more than they do in class discussions (Hsi & Hoadley, in press).

In summary, electronic and human resources in combination can scaffold students to become autonomous learners. Students learn how to (a) monitor their own learning, (b) organize and consider alternative accounts of phenomena, (c) distinguish ideas, and (d) appreciate the nature of a discipline when instruction is carefully designed. Distance learning, like other instruction, can scaffold learners. The challenge is to incorporate research on learning and instruction into design of distance learning environments. Rather than designing courses for autonomous learners, courses need to scaffold students so that they become autonomous. A process of trial and refinement of course options will be necessary to create scaffolded knowledge integration.

Designing Effective Distance Learning

How can the scaffolded knowledge integration framework help designers of distance learning environments? The framework provides some clues about important course design decisions, suggests ways to diagnose course weaknesses, and offers directions for course refinement. The scaffolded knowledge integration framework emerged from trial and refinement of a group of courses. Similarly, distance learning environments will require refinement to fully understand opportunities and drawbacks.

The framework helps designers encourage and sustain autonomous learning. Many straightforward elements of distance learning encourage passive or, as most, active learning. For example, stunning lectures, effective videos, clever multimedia presentations, or powerful explanations encourage passive learning. Passive students may report boredom, confusion, frustration, or all three. Passive students often fall asleep in class, skip classes altogether, or fail to complete assignments. Instructional designers may resort to "edutainment" to keep students awake, but passive learners will absorb little, as much research attests (e.g., Mason & Kaye, 1989). As Hawkridge (1995, p. 9) reports, "These courses usually have a small, vociferous and enthusiastic group of users, and a majority of non-users." A few users autonomously take advantage of presentations that others view passively. How can designers augment transmission of information to convert passive or active learners to autonomous learners? The following sections discuss science lectures on video, virtual class discussion, computer assisted courses, computer learning environments, and foreign language learning environments, all from the scaffolded knowledge integration perspective.

Taking Advantage of Science Lectures on Video

The Mechanical Universe television series, covering the first 2 years of college physics, is one of the most ambitious and comprehensive video courses ever developed. Led by Goodstein at the California Institute of Technology, with over 6 million dollars of funding from the Annenberg Foundation, the project includes 52 half-hour programs, two textbooks, a teacher's manual, and other materials including specially edited materials for high school use (Goodstein, 1990; Olenick, Apostol, & Goodstein, 1986). The authors of these materials recognize course limitations, noting that the important ideas of physics, "cannot be learned by simply watching television any more than they can be learned by simply listening to a classroom lecture. Mastering physics requires the active mental and physical effort of asking and answering questions, and especially of working out problems" (Olenick et al., 1986, p. xiii, reprinted with permission).

One successful use of these materials occurs at the University of California, Berkeley, where instructors in the minority education program show excerpts from the videodisc version of the programs to stimulate effective small group discussion and enhance tutoring (Beshears, 1991). Instructors take advantage of the social nature of learning by scheduling small groups to view and discuss short segments of the video. Discussions in tutoring sessions support students as they distinguish their own ideas from those on the videodisc. Tutors in the program also balance making thinking visible with encouraging autonomy. They use animations from the video to make complex physics ideas visible, they model physics problem solving to demonstrate ways for students to monitor progress, and they prompt students to try these ideas themselves in tutoring sessions.

These enhancements follow the scaffolded knowledge integration framework: They help students connect ideas from animations or explanations on the videodisc to their own ideas and they help students develop criteria for distinguishing ideas and resolving uncertainties. The videodisc materials could become a lifelong resource for students who might autonomously locate explanations or alternative perspectives on the videodisc when they have specific questions.

Using video materials to enhance group learning or as a source of explanations on demand takes advantage of the video format while also guiding learners to become autonomous. Rather than face-to-face meetings, distance learners could also convene in video conferences.

Virtual Class Discussion in Science Courses

To increase active learning, most lecturers provide opportunities for students to ask questions. Usually only a few students participate, and most participants are male (Wellesley College Center for Research on Women, 1992). Question and answer sessions may silence women students since instructors call on men more than women and ask men more abstract, complex questions than those posed to women (Sadker & Sadker, 1994). To increase active learning and provide realistic professional experiences, law faculty and others ask students questions rather than waiting for volunteers. Some classes rely solely on discussion, skipping lectures completely. Recently instructors have also interrupted lectures to ask each student to record answers to questions (Light, Singer, & Willett, 1990). Each of these practices helps to make students active learners, but might not encourage autonomy.

Distance learning course designers have experimented with a variety of electronic forms of discussion to achieve similar goals. Electronic mail and electronic bulletin boards allow students to interact with instructors or other students in ways that have many features in common with class discussion. Electronic discussions often silence female students just like traditional class discussions. Pilot research with the Multimedia Forum Kiosk mentioned earlier shows that females make more comments when they have the option of being anonymous than when all comments are attributed (Hsi & Hoadley, 1994). More research is needed to make discussions reflect the diversity of views held by students.

To improve on group discussion, several electronic approaches take advantage of remote experts and encourage students to specialize. For example, in the Virtual Discussion Group at the University of California at Berkeley (Autumn, 1995), students read papers by active biology researchers at institutions all over the world. Each week one of these experts agrees to participate in the class. Every student creates a list of questions for the expert so all students participate. The instructor eliminates overlapping questions and sends the list to the researcher as well as all class members. The instructor communicates with the expert while class members observe. Class members continue to communicate with each other and the instructor. This approach has several cognitive advantages over class discussion. First, all class members ask questions. Second, instructor and expert provide a model of professional discourse. Third, students participate as legitimate but peripheral contributors (Lave & Wenger, 1991). Preliminary research shows that students in the Virtual Discussion Group learn more than those in the traditional course (Autumn, 1995).

Two precollege programs, Kids as Global Scientists (Songer, 1993), and CoVis (Gordin, Polman, & Pea, 1994) vary the expertise of discussion participants to more closely emulate the character of scientific discussions. Both these projects feature discussions about the weather and involve expert meteorologists, who participate by answering questions and suggesting alternatives. In Kids as Global Scientists, students specialize in one aspect of the weather in their locality and discuss their findings with their peers in other geographical areas. One group of students might specialize in wind while another would examine cloud patterns. Following this approach, students carry out more complex discussions with their specialist counterparts than would be the case if they remained generalists. In these discussions, students become experts and can model their behavior on their observations of the expert meteorologist who participates in the discussion. Students report that they often understand complex ideas about weather phenomena better when they are expressed by their peers than when they are expressed by teachers or textbooks. Instead of privileging the teacher, these discussions distribute expertise in the group and engage students as both experts and learners.

To explore complex conversations, including conversation on the Internet, tools can structure discussion using spatial metaphors. For example, the Knowledge Integration Environment SpeakEasy in Figure 3 engages students, teachers, and natural scientists in expanding the repertoire of explanations for a scientific event and in distinguishing among them (Bell et al., 1995; Hoadley, Hsi, & Berman, 1995; Linn, 1996). As a group, participants contribute alternative interpretations to a question such as "How far does light go?" illustrated with multimedia evidence. SpeakEasy structures the discussion, guiding contributors to indicate when their comments reinforce, extend, or contradict those already in the discussion. Instructors using SpeakEasy can ask students to reflect and read comments by others before adding more comments. In electronic discussion, compared to class discussion, students are more likely to recognize that their peers disagree with them and to respond directly to a comment made by another student.

These improvements to class discussion follow the scaffolded knowledge integration framework in several ways. They help make thinking visible by modeling how experts discuss ideas and they encourage autonomy by supporting students as they emulate expert discussion practices. They make the social interactions of participants more productive by giving each participant expert status for some topic and allowing students to gain useful knowledge from each other. And they encourage autonomy by supporting students as they distinguish their ideas from those of their peers.

Computer-Assisted Instruction in Mathematics, Science, and Decision-Making

Distance learning environments in mathematics, science, and decision-making include both traditional computer-assisted instruction where students respond to questions and get feedback as well as more technology-enhanced multimedia scenarios where students combine information to make decisions. Correspondence courses have followed these practices for more than 100 years (Wright, 1991; Young & McMahon, 1991). Successful electronic courses exist in mathematics, (McArthur, Stasz, & Zmuidzinas, 1990; Suppes & Morningstar, 1972), programming (Anderson, Conrad, & Corbett, 1989; Johnson & Soloway, 1985; Reiser, 1988; Reiser, Kimberg, Lovett, & Ranney, 1992), logic (Suppes & Morningstar, 1972), physics (Sherwood & Larkin, 1989; Smith & Sherwood, 1976), and other domains.

For example, Anderson and his colleagues have created extremely powerful tutors for algebra word problems, geometry proofs, and LISP programming (Anderson et al., 1985). These tutors pose problems and provide feedback on student solutions rather than using the traditional multiple choice format. They encourage students to plan their approach and to implement each step of their plan. After each line of the solution, the tutor responds with feedback and guidance. In addition, students solve problems on their own and rely on instructors for help if necessary. These tutors succeed for some students. Others find these tutors frustrating because their creative solutions get rejected after only a few steps. For example, Reiser reports that some students believe that the LISP tutor accepts only a subset of correct responses. These students lack methods for testing their conjectures and may believe in a solution even when the tutor rejects it, or assume an incorrect solution would succeed with a more powerful computer. Instructors can incorporate computer tutors into effective courses but need to help students develop self-monitoring and critiquing skills in addition. Research on this aspect of learning is on-going for the LISP tutor (e.g., Bielaczyc, Pirolli, & Brown, 1995).

Computer-assisted instructional courses typically undergo extensive testing to ensure that they have attainable goals for students and meet those goals (Moar et al., 1992). Most course designers diagnose student difficulties and revise the course to meet student needs. For students who fail traditional mathematics and science courses, remedial computer-assisted instruction might

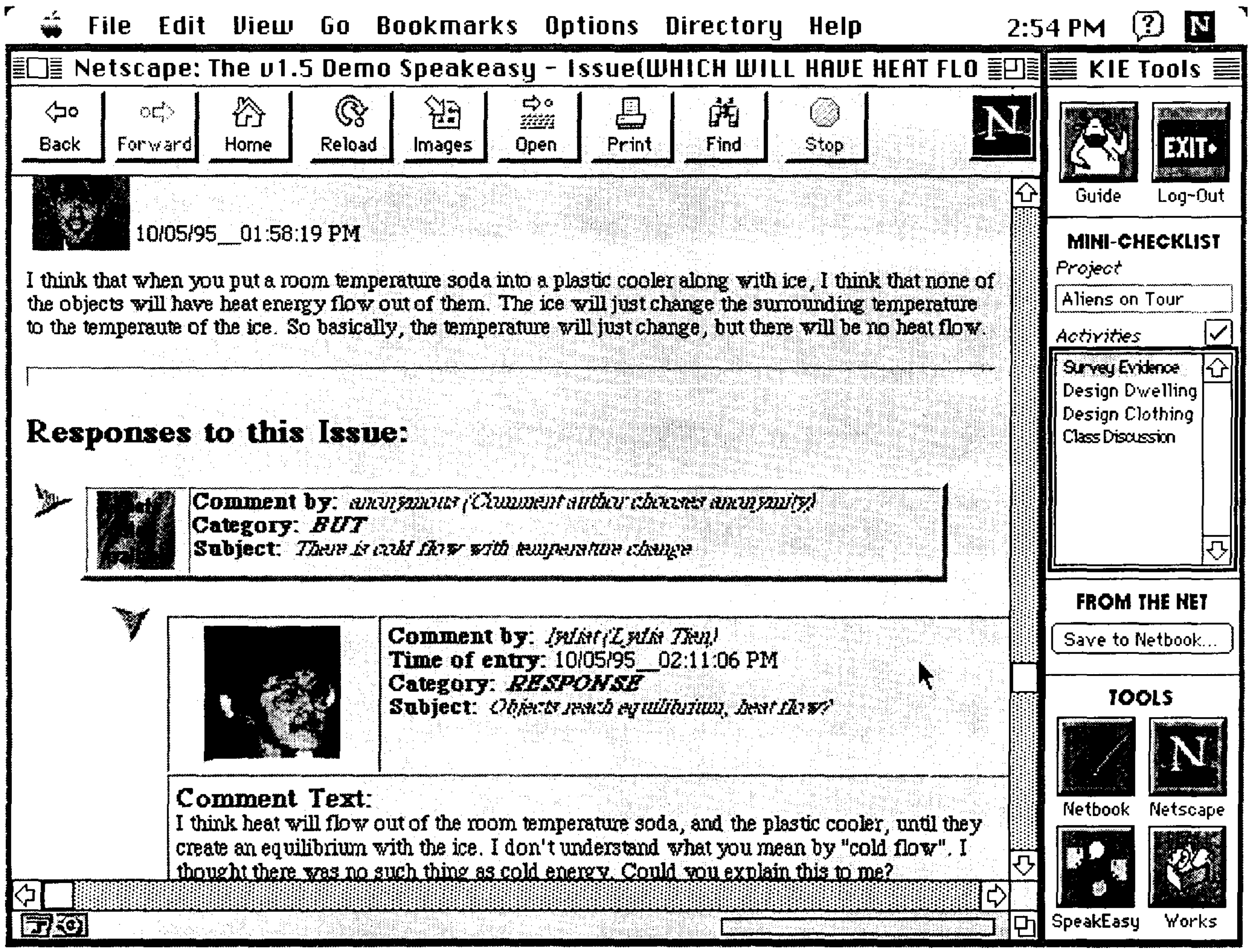

FIG. 3. The SpeakEasy stimulates discussion with multimedia evidence and structures contributions to help students respond to ideas raised by others.

succeed because course refinement addresses their needs in ways the traditional course overlooks.

Several lessons learned from analyzing computer-assisted courses underscore the value of the scaffolded knowledge integration framework. First, computer assisted courses may have convenient rather than accessible goals. Courses in mathematics, science, and decision-making lend themselves to computer delivery, because computers can evaluate a range of "legal" responses. Designers might select course goals that require active, rather than autonomous learning. Short answers are easier than open-ended responses for computers to interpret. Drill and practice are excellent techniques for fostering memorization, but may deter students from reflecting and connecting ideas. Students may come to believe that all problems can be solved in less than 5 minutes, may lack an understanding of the broader issues and methodologies in the discipline, and may fail when asked to carry out projects, larger assignments, or critiques of experiments. The course might oversimplify the materials such that students cannot apply the principles and ideas when reading news articles or encountering more complex and ambiguous everyday problems.

Second, computer assisted courses succeed by motivating students to respond actively to questions, but vary in their ability to motivate students to autonomously take responsibility for their own learning. Active button pushing, question answering, or experimentation may lull students into complacency, rather than motivating them to connect their ideas, to reflect on their own understanding, or to diagnose weaknesses in their preparation. Students may memorize or isolate new information rather than linking and connecting it.

Third, some autonomous learners may feel stifled by the small steps and continuous monitoring in computer-assisted courses (Doyle, 1983). Research shows that the most knowledgeable students become frustrated if they cannot modify courses to meet their own needs, perhaps identifying a different textbook or forming independent study groups.

Computer Learning Environments

How can computers help promote autonomy? Rather than providing direct feedback, as found in computer-assisted courses, a class of computer learning environments encourages autonomy by helping students learn to diagnose their own progress and gain an understanding of the nature of the discipline. Microworlds such as the dynaturtle (diSessa, 1979) and ThinkerTools (White, 1993) for mechanics, the Geometry Supposer (Schwartz, Yerushalmy, & Wilson, 1993; Schwartz, 1995), Green Globs for algebra (Dugdale & Kibbe, 1983), or Electronic Pinball for electricity (Chabay & Sherwood, 1995) guide student activity towards identifying principles that govern observable events. In these environments, students make predictions about a topic such as motion in a plane and test their ideas using the microworld. Recently, White (in press) and Schecker (in press) also engaged students in carrying out experiments about personally interesting phenomena such as the behavior of a soccer ball and then modeling the situation using the microworld. In these cases, students solve problems and reconcile the results of the simulation with the results of their experiment. They grapple with aspects of science such as the precision of measurement or the role of unanticipated factors. Similar courses using modeling environments in physiology (Kuo, 1988; McGrath, 1988) and biology (Beshears, 1990, 1992) demonstrate the power of this approach for a wide range of disciplines.

Computer environments can also encourage autonomous learning by helping students organize their problem solving. For example, the Knowledge Integration Environment (see Fig. 4) includes a checklist of activities and the cow guide to help students figure out what to do in order to carry out the activity. This approach can scaffold activities that contribute to autonomous learning such as determining criteria for success, comparing solutions, and critiquing solutions generated by others.

Another approach to encouraging autonomy occurs in self-paced courses where students study material independently but take regular quizzes and get guidance. Here students learn how to learn autonomously from the guidance after they complete each quiz. Clancy and others design self-paced programming courses that include online and print case studies to guide students between quizzes (Clancy & Linn, 1990, 1992b; Davis et al., 1993; Mann, Linn, & Clancy, 1994). As is found for most computer-delivered courses, more students start the course than complete the course and many students spread the course over more semesters than would be possible with the traditional one. Students in these courses perform as well as, or better than, those in the traditional course on final projects and the final examination. These courses prepare students for the next programming course at least as well as traditional courses and offer some economies.

Empire State University takes a similar self-paced approach without using computer learning environments (Boyer, 1989). Students enrolling at Empire State meet with instructors in person or by phone to set up a course plan and have regular subsequent meetings. Instructors help students set goals and monitor progress and students use books, videos, museum visits, and other activities to gather information. Instructors guide, critiquing student work, or modeling the process of knowledge integration. Taking advantage of social contributions to learning, such as reconciling views held by many students, occurs informally and may require student initiative. Empire State makes economic sense by eliminating costs for classrooms and student facilities. In this model, faculty instruct a modest number of students, redesign courses if students encounter problems and monitor student progress carefully. Empire State University attracts mature students who have part-time or full-time jobs and want to improve their skills. These students are already likely to take an autonomous stance towards their courses. Empire State instructors are empowered to guide students and to personalize courses to meet student need so they can scaffold students toward autonomy. Nevertheless, many students fail to complete courses. Instructors might amplify their effectiveness by using computer environments to intensify student scaffolding.

In summary, computer learning environments offer considerable promise for designing effective science and mathematics courses. A number of promising components and models exist. Yet, design of computer learning environments remains a process of iterative improvement. From the distance standpoint, designers can use computer scaffolding and guidance to free teachers for more creative and effective tutoring and troubleshooting. Remote students can use the learning environment over the network and interact with instructors by electronic mail, video conferences, or telephone. Instructors can interact with students as well as diagnose weaknesses in the computer learning environment. Designers can use feedback from instructors to improve courses. And many institutions might jointly create such environments and personalize them for local circumstances.

Foreign Language Learning Environments

A plethora of recent language teaching innovations lend themselves to distance learning (Garrett, Dominguez, & Noblitt, 1989; Maxon, 1994). Several environments make language use visible and engage students in problem solving. Numerous programs take advantage of the social nature of learning.

To make language use visible to students, instructors have traditionally used video, news clips, and movies. Today, students can access international news broadcasts in university media centers, rent international films at local video stores, and make their own videos in a variety of languages for remote colleagues (Barson, From-

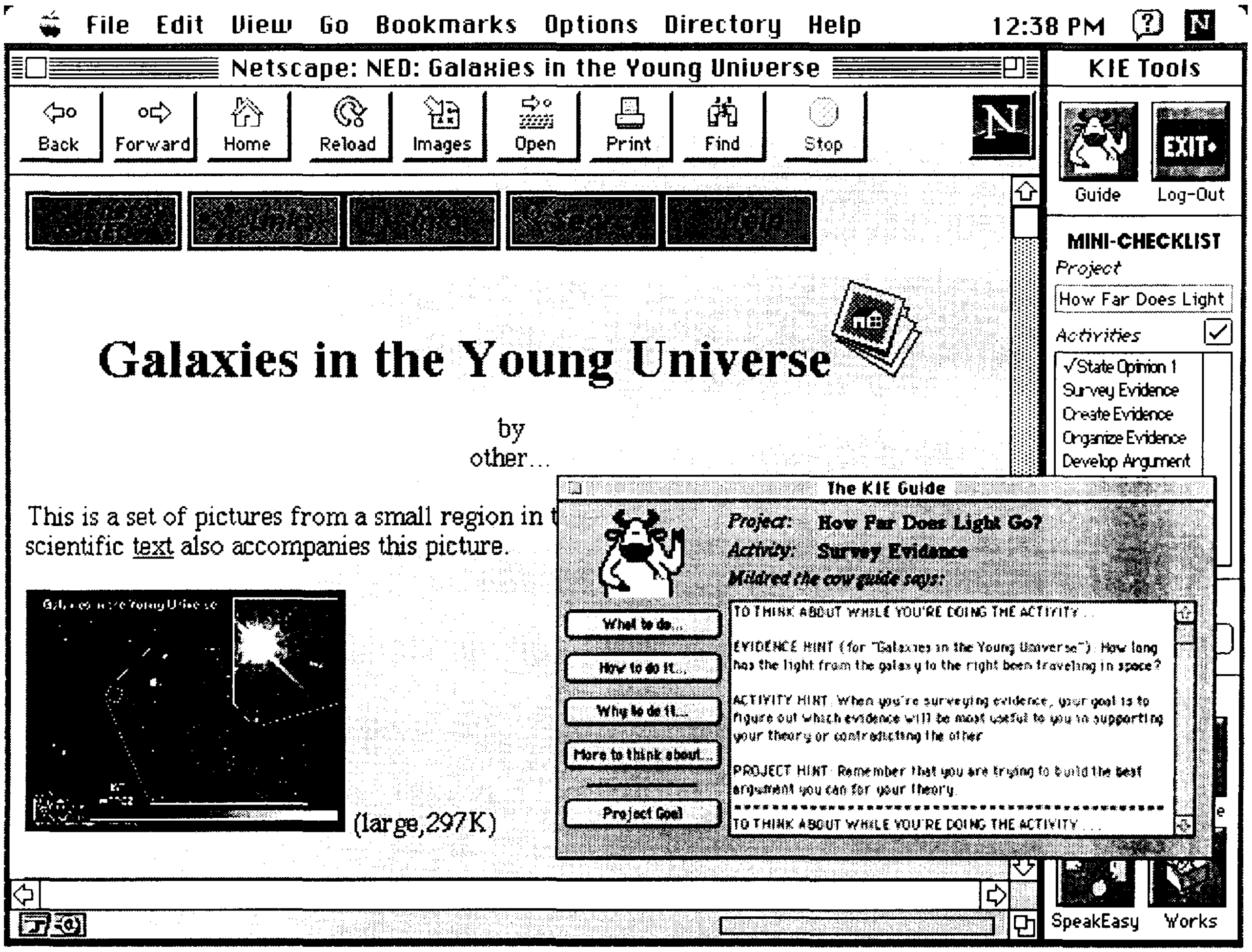

FIG. 4. In the Knowledge Integration Environment, a checklist guides learner activity, and Mildred the cow guide helps students become autonomous learners.

mer, & Schwartz, 1993). They can post contributions on the World Wide Web and access colloquial language electronically as well as traditionally. Electronic media make language materials more accessible to students. Some recent software uses multimedia to place students in authentic conversations (Thorne, 1994).

Several groups have created language software that take advantage of multimedia. For example, at a recent conference, three alternative Mandarin Tone Tutors were presented. The University of California, Berkeley version, shown in Figure 5, helps students organize their knowledge, autonomously design lessons for themselves, and independently test their knowledge. The Mandarin Tone Tutor was created by a partnership including Professor Sam Chung in Asian Languages, Owen McGrath, a pedagogy expert at the Instructional Technology Program, Howie Lan, a Mandarin speaker trained in computer science, Jeff Rusch, a designer, and others. This team jointly planned and iteratively refined the program. The program helps students organize their Mandarin knowledge by displaying the structure of the language. Both instructors and students can use the software to design lessons. Students can easily create their own lessons based on the structure. They can use the software to practice recognizing, pronouncing, and discriminating tones. Research on the Mandarin Tone Tutor (Ni, 1995) demonstrates that students find the software useful and have numerous suggestions for improvements. These are being implemented.

To take advantage of the social nature of language learning, several electronic communication approaches offer promise. For example, netpals have replaced penpals in many courses (McGrath, 1995). Electronic communication in French, Italian, Spanish, and other languages has immediacy that traditional letters lack. Netpals discuss current events just as they happen and provide timely insights for courses. Instructors also use computer laboratories for simultaneous written communication about current topics to improve written communication. The Daedalus Integrated Learning Environment supports this approach as used at the University of California by Professor Rick Kern (Thorne, 1994).

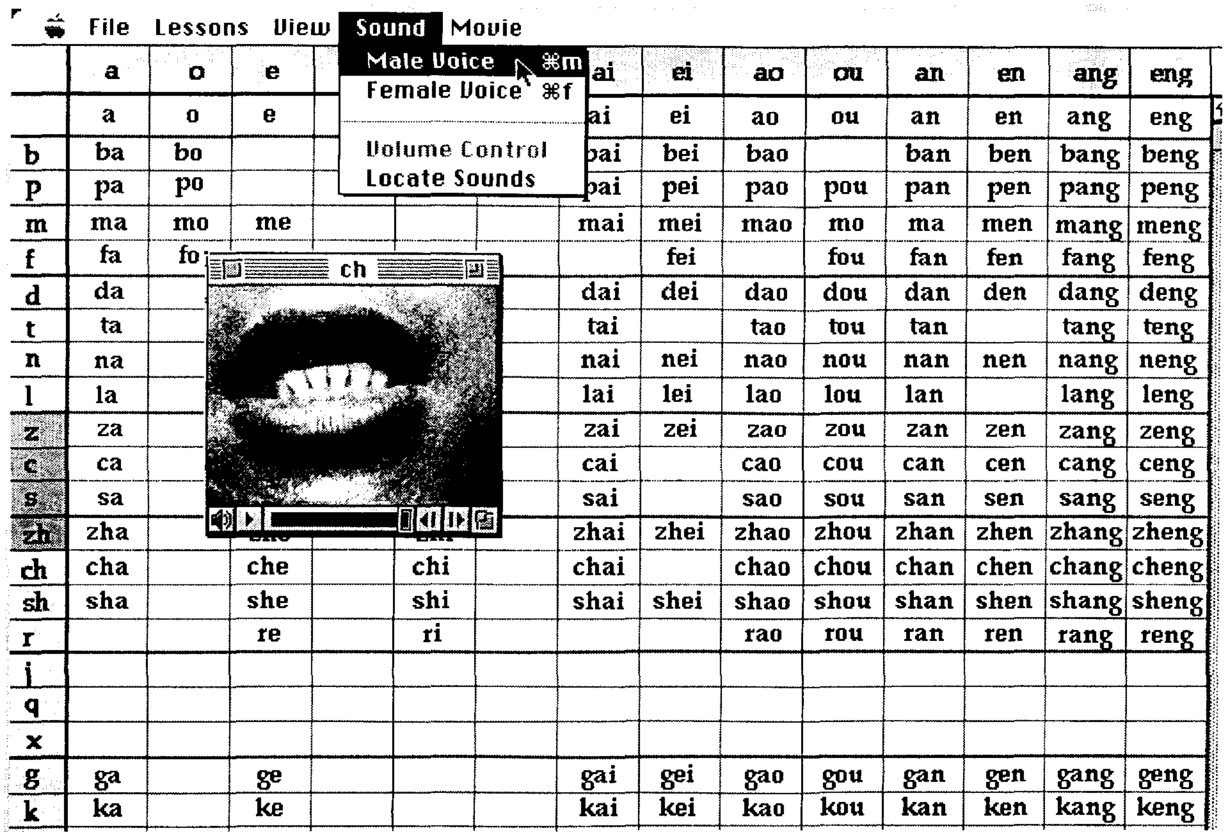

FIG. 5. The Mandarin Tone Tutor structures student understanding and allows students to create personalized lessons.

Kern reports that students write better under these circumstances than when they prepare homework assignments by themselves. When students use these electronic resources to communicate in another language, they write for peers and build relationships with their correspondents that go beyond traditional written assignments.

In addition, World Wide Web sites have become a valuable resource for language courses. Students can access recent, varied, and colloquial uses of languages on the World Wide Web. And, students can create multimedia materials and post them for their international peers. Technical mechanisms for supporting varied character sets expand regularly.

These innovations coincide with elements of the scaffolded knowledge integration framework. In traditional language instruction, drill software often relies primarily on making students active without also targeting this activity to integrated understanding as noted for science and mathematics in the previous section. Replacing drill with practice in authentic conversations increases the likelihood that ideas will be linked and connected to each other and to situations where they apply. Models of sound language use also make language practices visible. And students can use these models when they autonomously create their own newscasts or films. Taking advantage of the social nature of learning makes a great deal of sense in language instruction since social cues contribute to language comprehension as well as to language production. When students write to an audience of peers, they take into account the needs of their correspondents and get convincing feedback on their effectiveness.

Conclusions

Instructors often design courses for transmission of information, and students regularly adopt a passive stance towards learning, resulting in poor student performance. Since transmitting information via text, video, lecture, computer-assisted instruction, or some combination makes more economic sense than guiding students individually or in small groups, distance learning course designers may rely on transmission even more than those designing traditional courses. Furthermore, the students who take an autonomous stance towards a course emphasizing transmission often lull instructional designers into complacency. However, most students need guidance to take an autonomous stance towards a course; neglecting such guidance ultimately wastes education dollars by increasing enrollment in remedial courses and by deterring talented students from persisting in a course of study.

The most effective student guidance promotes autonomy by supporting students as they explore alternatives, gain a sense of the discipline, and develop criteria for monitoring their own progress. Incorporating such guidance into distance learning requires serious attention of course designers. Some students demand guidance from instructors, peers, family, or outside experts and succeed even when courses fail to provide support. Responsible instructors know that neglecting student guidance rewards aggressive students who may not be the most talented (e.g., Linn, 1994), and leaves many students unprepared for the next course.

To develop a student's autonomous learning ability in a discipline requires creative instructional design and iterative course refinement based on analysis of student performance and of the discipline. As illustrated in the 10-year-long research on the Computer as Learning Partner curriculum, the scaffolded knowledge integration framework can guide designers. In addition, as depicted in the history of programming instruction (e.g., Linn & Clancy, 1992a), each discipline requires specialized analysis. For example, monitoring one's progress in programming involves recognizing a small set of abstract code patterns along with their conditions of reuse. Literature courses require students to detect a broad range of historical or mythological references and to look for themes from psychological work. As more and more designers engage in refinement of distance learning, it will be possible to make more detailed course design recommendations.

The scaffolded knowledge integration framework abstracts principles to help distance learning designers guide learners. This framework guides designers to orchestrate environments that go beyond transmitting information or engaging students in unfocused activities and instead support learners as they create their own understanding and develop criteria for monitoring their performance.

The four elements of the scaffolded knowledge integration framework work in concert:

1) Accessible course goals;
2) making thinking visible;
3) encouraging autonomy; and
4) social nature of learning.

To implement the first element, for example, electronic distance course designers need to make sure students have the verbal skills and other support necessary to discuss issues relevant to the goals. Otherwise the course might have accessible goals but not take advantage of the fourth framework element. Courses need to address both the element of making thinking visible and the element of encouraging autonomy to balance transmission of information with opportunities for students to reflect, criticize, and monitor progress. And, all four elements need to complement each other to ensure that students integrate their ideas rather than memorizing or isolating knowledge.

Implementing the scaffolded knowledge integration framework works best when a team of designers, representing the diverse expertise necessary for creating and refining a course, collaborate in an atmosphere of mutual respect. Experts in the discipline contribute knowledge of the field and help interpret students responses. Experts in pedagogy bring an assortment of instructional alternatives and can help determine whether the new environments succeed. Experts in technology bring a range of electronic resources as well as understanding of logistic issues. Materials designers bring expertise in computer screen layout. Design partnerships may also draw in other experts to create effective courses. By working together, teams balance the contributions of pedagogy, technology, disciplinary advances, and other factors, and prevent the development of courses that are solely driven by one element such as technology.

How can such teams make economic sense? Clearly teams need to build on each other's experience. Often, as in the case of the three Mandarin tone tutors, groups work in isolation. This issue of *Perspectives* contributes to creating a community of designers who jointly tackle instructional challenges. Forming consortia from several institutions, such as the Synthesis Coalition in Engineering (Agogino & Ingraffea, 1992), to improve courses nationally also helps build community. Forming partnerships among experts in pedagogy and experts in other disciplines often succeeds on college campuses and in precollege course reform. To realize the benefits of distance education and create lifelong learners, the discipline of distance learning course design needs support and nurturing. As a start, a forum for communicating successes and failures is needed.

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