DOCUMENT RESUME

ED 357 733 IR 016 092

AUTHOR	Collins, Allan
TITLE	Design Issues for Learning Environments.
INSTITUTION	Center for Technology in Education, New York, NY.
SPONS AGENCY	Office of Educational Research and Improvement (ED), Washington, DC.
REPORT NO	CTE-TR-27
PUB DATE	Apr 93
CONTRACT	OERI-1-135562167-A1
NOTE	11p.
PUB TYPE	Information Analyses (070) -- Viewpoints (Opinion/Position Papers, Essays, etc.) (120) -- Reports - Descriptive (141)
EDRS PRICE	MF01/PC01 Plus Postage.
DESCRIPTORS	Cognitive Style; *Cost Effectiveness; Curriculum Design; *Decision Making; *Educational Environment; Educational Experience; Educational Objectives; Elementary Secondary Education; *Instructional Design; Interaction; Knowledge Level; Learner Controlled Instruction; *Learning; Modeling (Psychology); *Teaching Methods
IDENTIFIERS	Coaching; Cognitive Apprenticeships; ID Expert; *Learning Environments; Reflective Thinking; Scaffolding

ABSTRACT

This paper explores issues that designers of learning environments should consider, omitting issues about knowledge learned and the social settings in which learning occurs that are addressed elsewhere. The perspective taken on design is to think of each decision in terms of its costs and benefits, an approach that may allow designers to minimize costs and maximize benefits of design decisions. The first issue to address in the design of any learning environment is authenticity, and the goal of authenticity is to prepare students to do the kinds of complex tasks that occur in life. The cost-benefit trade-offs that are dealt with in this paper are organized under four topics: (1) goals; (2) learning style; (3) sequence; and (4) methods. Learning goals that should be considered are those of memorization versus thoughtfulness, whole tasks versus component skills tasks, breadth versus depth of knowledge, diverse versus uniform expertise, access versus understanding, and cognitive versus physical fidelity. Learning style issues include interactive versus active versus passive learning, incidental versus direct learning, natural versus efficient learning, and whether or not the learner is in control. Because a learning environment changes as a person interacts with it, some of the design tradeoffs must be considered sequentially; hence, it is proposed that the trade-offs between grounded versus abstract learning, structured versus exploratory learning, systematic versus diverse learning, and simple versus complex learning be treated this way. And, finally, in regard to methods, the following teaching methods that are associated with cognitive apprenticeship and the design of learning environments may be considered by the designer: (1) modeling; (2) scaffolding; (3) coaching; (4) articulation; and (5) reflection. (Contains 32 references.) (SLD)

CENTER FOR TECHNOLOGY

Design Issues for Learning Environments

Allan Collins
Bolt Beranek and Newman
Northwestern University

BANK STREET COLLEGE OF EDUCATION
610 WEST 112th STREET
NEW YORK, NY 10025

Technical
Report
Series

CENTER FOR TECHNOLOGY IN EDUCATION

Technical Report No. 27

Design Issues for Learning Environments

Allan Collins
Bolt Beranek and Newman
Northwestern University

April 1993

Allan Collins
Bolt Beranek and Newman
Northwestern University

When designing a learning environment, whether computer based or not, there are a multitude of design decisions that must be made. Many of these design decisions are made unconsciously without any articulated view of the issues being addressed or the tradeoffs involved. It would be better if these design decisions were consciously considered, rather than unconsciously made.

The perspective I take on design is to think of each decision in terms of its costs and benefits. From this perspective, the crucial issues are: What are the issues that must be addressed in designing learning environments? What are the cost–benefit tradeoffs associated with each design issue? How should the costs and benefits be weighed? In this paper I do not try to discuss these issues in detail; my goal is only to raise a set of issues and some of the cost–benefit tradeoffs that arise with respect to each issue.

The first issue to address in the design of any learning environment is what is called authenticity (Brown, Collins, & Duguid, 1989; Wiggins, 1989). The questions associated with authenticity are: What are the potential uses for the knowledge? How can a learning environment be created that reflects those possible uses? Too much of what we teach in school is taught because it has always been taught. We need to rethink what students should learn in order to live in the twenty-first century. For example, should we spend twelve years teaching students mathematical algorithms that computer tools can carry out for them? The goal of authenticity is to prepare students to do the kinds of complex tasks that occur in life. Much of what is learned in school is never used, because it is often the wrong knowledge for the modern world, and even when it is the right knowledge, people do not know how to apply it.

I have organized the set of tradeoffs under four general topics: (1) goals, (2) learning style, (3) sequence, and (4) methods. A similar analysis could be applied to the kinds of knowledge students learn and the social settings in which they learn.

Learning Goals

The first set of tradeoffs designers need to address have to do with their goals for what students should learn. The tradeoffs I address in this section are: memorization vs. thoughtfulness; whole tasks vs. component skills; breadth vs. depth of knowledge; diverse vs. uniform expertise; access vs. understanding; and cognitive vs. physical fidelity.

Memorization Versus Thoughtfulness

There is a tension throughout school between students memorizing things in order to do tasks fast and

To appear in S. Vosniadou (Ed.), Psychological and Educational Foundations of Technology-Based Education, *New York: Springer-Verlag. This work was supported by the Center for Technology in Education under Grant No. 1-135562167-A1 from the Office of Educational Research and Improvement, U.S. Department of Education, to Bank Street College of Education. I thank Roy Pea for his suggestion of adding* Access vs. Understanding *and* Depth vs. Breadth of Knowledge *to the set of issues.*

easily, such as memorizing the multiplication table, and learning to do things thoughtfully, such as solving complex problems. To the degree that one knows how to do something automatically (e.g., decoding), it can free the mind to be thoughtful about other things (e.g., the meaning of the text).

To illustrate the issue, the superintendent in Manchester, New Hampshire in the 1930s persuaded some of his teachers to give up teaching math algorithms for the first five years of school and focus instead on math discussion and estimation tasks (Benezet, 1935). When he visited schools, he would give students problems such as: "If half a stick is buried in mud, two–thirds of the rest is under water, and one foot is above water, how long is the stick?" Students who were taught in the traditional manner would start adding or multiplying the numbers given, whereas the students taught in the new manner would reason through the problem. He clearly had opted for thoughtfulness over memorization.

Some of the costs of memorization are evident in the examples: it leads to inflexible use of the memorized knowledge and to reliance on drill and practice, which is unmotivating for students. The benefits are that the skills that are memorized can be offloaded to free the mind for thinking. The mastery of knowledge and skills by memorization is also empowering for students. Gaining automaticity is crucial if one is going to use a particular skill a lot. But if one will hardly ever use a skill (such as multiplying fractions), then memorization is not worthwhile. When automaticity is appropriate, it is best gained by creating practice environments that reflect the uses of the skill in the world.

Whole Tasks Versus Component Skills Tasks

There is a tradeoff between having students perform whole tasks that require integration of a variety of skills vs. having students perform simplified tasks that focus on particular subskills. For example, one can have students practice sounding out different phonic patterns or one can have them read Dr. Seuss books for enjoyment. There is a tendency in school to break everything into easy components, but it is often impossible to tell what the components are good for. Much of school is like having students practice the forehand, backhand, and serve needed for tennis, without letting them know what the game is.

The costs of giving students whole tasks are that it is difficult to focus on particular weaknesses; it is difficult to manage the whole process at once; and there is always a chance of failure when the task is too complex. The benefits of whole tasks are that it is easy to see the point of the exercise; it is possible to practice the integrative skills that are necessary; and one is unlikely to develop strategies (as students do for component skills tasks) that are counterproductive to the task as a whole.

It seems clear that focusing on subskills is sometimes very productive, but ideally this should occur when a weakness has been diagnosed. Scaffolding (Collins, Brown, & Newman, 1989; Palincsar & Brown, 1984) permits even weak students to accomplish whole tasks from the beginning. One strategy is to start by scaffolding students in whole tasks, going to component tasks when they seem appropriate.

Breadth Versus Depth of Knowledge

The issue is whether we want students to learn a little about a lot of things, as Hirsch (1987) argues in his plea for cultural literacy, or whether we want them to understand a few topics deeply. Our society tends to pay specialists more than generalists, and yet the pressures on school are to include more and more information in the curriculum.

The costs of breadth are that students do not get an authentic feel for any subject and that a demand for breadth often gets turned into requirements that students learn particular things. The benefits of breadth include cultural literacy, which, as Hirsch (1987) argues, is critical for people to understand each other. Also, students are exposed to many different ideas so that they can make knowledgeable choices about which interests to pursue. Finally, breadth allows one to make connections between many different disciplines, which can provide novel insights. A possible compromise between breadth and depth is to pursue a few topics in depth, while broadly covering a wide variety of topics. Some students should become specialists and some generalists, and learning environments should support both goals.

Diverse Versus Uniform Expertise

Most schools attempt to ensure that all students learn the same thing. An alternative goal is for students to gain diverse expertise. This difference has profound effects on the organization of learning. For example, in Discover Rochester, Carver (1990; Collins, Hawkins, & Carver, 1991) had eighth graders conduct research on different aspects of Rochester, New York—such as the history, climate, culture, and government of the city—in order to produce a HyperCard exhibit for the Rochester Museum and Science Center. Students specialized in different content areas and in different tasks (e.g., producing text vs. graphics for the exhibit). The traditional school approach would have students read and discuss the same material on these topics.

One cost of diverse expertise is the loss of a community of shared knowledge, where students can discuss issues from similar backgrounds. Another cost is that teachers can no longer evaluate students in the same terms; that is, whether they have learned particular content or skills. The benefits are that students can specialize in what interests them and will feel pride of ownership in the knowledge and skills they have, that others do not have. It can also be viewed as a benefit that teachers cannot measure students on a simple metric, such as how much specific content they have gained, but rather must judge them in terms of their products and efforts (Collins, 1990). Our best examples of teaching (Lampert, 1986; Resnick, Bill, Lesgold, & Leer, 1991; Stigler & Perry, 1988) rely on uniform expertise, but the introduction of new technology and a constructivist pedagogy fosters a change to an emphasis on diverse expertise (Brown, 1992).

Access Versus Understanding

As we give students more powerful tools, understanding of the ideas and procedures that the tools accomplish for us is lost. For example, if we give students tools that fix the spelling and grammar in text, or that compute all the math algorithms in school, then knowledge of how to do such things will die out among students.

The costs of giving students access to powerful tools is that students will not understand how these tools work and will not be able to evaluate the products derived from the tools. The benefits of giving students access to powerful tools is that they can get on with learning what they will need for the future instead of learning spelling and algorithms. Furthermore, they will be vastly empowered by having tools that do for them what people are not so good at doing. History is replete with lost understandings: for example, how to grow crops and make clothes were once taught to practically everyone, and it seems inevitable that much of what we now teach in school will not be learned by most people in the future.

Cognitive Versus Physical Fidelity

As we create simulated environments, either on or off computers, a critical question becomes the tradeoff between preserving physical fidelity to the environment vs. preserving only cognitive fidelity. This tradeoff is well illustrated by the difference between a simulation of the steam plant on board ships built by the Navy, which preserves all the physical details, filling two large rooms and requiring a crew of eight people to operate. This can be contrasted to the cognitive simulation in STEAMER (Stevens & Roberts, 1983) which shows the configuration of the entire system and its different subsystems, as well as the flow of water and steam inside the pipes. It is much easier to understand the system from working with the cognitive simulation, but much of the physical detail is lost.

The costs of stressing cognitive fidelity are that learners may not recognize particular situations in the real world, since they look different than in the simulation. Another problem is that important mappings that are used for understanding a system may be lost: any simulation that throws away a large portion of the mapping to reality risks throwing away some critical elements that people rely on. The benefit of stressing cognitive simulation is that it makes it possible to focus on salient aspects of the situation, so that students do not get lost in complexity. Moreover, cognitive simulations are much cheaper to build. It pays to start with cognitive fidelity so that students get the big picture, and then move to greater physical fidelity.

Learning Style

There are a number of tradeoffs that have to do with the learning styles of different students. These include whether the learning is highly interactive or not, incidental or direct, fun or serious, natural or efficient, and whether the learner is in control or not.

Interactive Versus Active Versus Passive Learning

There is a difference between active learning and interactive learning that is often overlooked. It is the difference between being in a highly responsive environment, such as playing a video game, vs. being in a fairly nonresponsive environment, such as working with a drawing program or LOGO (Harel, 1990). Both are very different from passive learning, such as watching a demonstration on the Visual Almanac.

The costs and benefits of active learning vs. passive learning are probably well known, but the costs and benefits of interactive learning vs. active learning are less well known. The costs of high interactivity are a lack of thoughtfulness by the student, because things move fast, and a lack of problem finding and construction by students, since everything they do is responsive to some situation. The benefits of high interactivity are that students receive immediate feedback on the success of their actions, they find such environments extremely motivating, and they are very active trying out different skills and strategies. Clearly, there needs to be a mix of highly interactive and not so interactive environments for learning. Less interactive environments foster thoughtfulness, while more interactive environments foster automaticity.

Incidental Versus Direct Learning

When you put students in a task environment, what you want them to learn may be taught directly by the task itself or only incidentally to the task. For example, Carmen San Diego is designed to teach knowledge about geography incidentally to tracking down criminals, whereas a travel agent simulation program where students find places to visit meeting different specifications (warm climate, inexpensive) would teach about the uses of geographical knowledge directly. It is possible to create very engaging tasks if you are willing to teach indirectly rather than directly.

The costs of incidental learning are subtle and have to do with authenticity. To the degree that one teaches indirectly, it is likely to promote the wrong lessons: as in Carmen San Diego, the geographical facts are mostly useless (e.g., that they speak French in Cameroon) and are not integrated in any well-organized structure. So the knowledge gained is not likely to be of much use when trying to do any task that requires geographical knowledge. But of course, the benefit is that the task is likely to be engaging, and so students will spend more time at it and perhaps learn more geography. My own preference is to create as engaging tasks as possible that reflect the uses of geographical knowledge, and let any facts and concepts be learned incidentally.

Fun Versus Serious Learning

There is a tendency to think that it is good for learning to be fun, but there is a downside. The costs are that students do not take what they are learning seriously and so may not remember it. Nor do they learn to force themselves to do difficult tasks. They come to think that all learning should be fun, but unfortunately life is not like that. The benefits are that you reach more students and they will spend extra time and effort. Furthermore, the repetitive drill and difficult tasks in school manage to turn off many students to education generally.

My own view is that it is best to engage students not by creating fun environments, but by creating meaningful tasks. An example is the project in Mississippi where African American students collected oral histories from adults who lived through the civil rights struggles of the 1960s, which they published as a book. This was a serious task, but it was as engaging as any fun task.

Natural Versus Efficient Learning

Most of the natural ways we learn things are inefficient and so there is always a tendency to try to design more efficient learning environments. For example, the way we first learn language in the home is very different from the more efficient ways we try to teach adults a second language. And the learning children do when they invent arithmetic algorithms is very different from the learning of the standard algorithms in school.

The cost of naturalness is simply its inefficiency: it takes children years to learn to speak their language. Nor do people naturally learn the most effective ways to do things, as with arithmetic. The benefit is that natural learning is functional: such learning enables people to achieve their goals so that the success rate is high. And they do not learn the kinds of counterproductive strategies that Schoenfeld (1985) describes for school math learning. Sacrificing naturalness is probably fine as long as we do not sacrifice functionality for the learner.

Learner Control Versus Computer or Teacher Control

There is a tradeoff between putting the learner in control of his or her own learning vs. keeping control by the teacher or computer. Exploratory environments (e.g., Physics Explorer) and tool-based projects (e.g., Discover Rochester) largely give control to students, whereas intelligent tutoring systems such as the LISP, geometry, and algebra tutors built by Anderson and his colleagues (e.g., Anderson, Boyle, & Reiser, 1985) keep rather tight control over what the student can do.

The cost of giving learners control is that most lack knowledge about the structure of the domain, and about how to learn effectively, and even about what they know vs. what they do not know. So they make poor educational choices for themselves. But the benefit of giving learners control is that they can study what is most interesting and challenging to them. Furthermore, control over their own learning is motivating in itself to many students. One strategy is to give students control over everything but pedagogical decisions; another is to give students information to help them make good pedagogical decisions (Fredericksen & White, 1990).

Sequence

Because a learning environment changes as a person interacts with it, one way to treat some of the tradeoffs is sequentially. I propose that the tradeoffs between grounded vs. abstract learning, structured vs. exploratory learning, systematic vs. diverse learning, and simple vs. complex learning be treated in this way.

Grounded Versus Abstract Learning

Learning contexts can mimic the situations in which the knowledge is likely to be used or they can be abstracted from particular situations. For example, in order to teach arithmetic, we can put students in the context of running a bank or building a clubhouse as Dewey did in his school (Cuban 1984), which are grounded in particular situations. Alternatively, we can teach them abstract algorithms that can be used in any context.

The costs of grounded learning derive from the fact that students' knowledge is tied to particular situations, and so they neither learn a general framework nor how to apply their learning to new situations. The benefits of grounded learning are that students see the point of what they are learning and learn at least one way to use their knowledge. Furthermore, it is difficult to remember abstractions if they are not grounded in situations that are memorable.

Currently, mathematics education starts with abstract algorithms, and then teaches students how to apply these abstractions in particular situations, through story problems. We have argued elsewhere (Brown, Collins, & Duguid, 1989) that this is backwards. Students should first learn knowledge and skills in context, and by experiencing multiple contexts they should learn to generalize their knowledge.

Structured Versus Exploratory Learning

Highly structured learning environments keep students engaged in activities that can lead to learning. For example, the LISP, geometry, and algebra tutors built by Anderson and his colleagues (Anderson, Boyle, & Reiser, 1985) provide immediate feedback and correction in response to students' mistakes, and thereby keep students from going off the correct solution path. Other systems, such as Physics Explorer and Interactive Physics, allow students much more flexibility to explore and even play, though Physics Explorer does allow teachers to set up structured exercises for students.

The costs of structured learning environments are that students do not learn to find their own problems and they do not learn to explore productively. The benefits of structured environments are that students do not end up floundering or randomly playing, and they are not as likely to get turned off by failure. Ideally, students would start out in highly structured environments and, as they master the skills of the domain, move to less and less structured environments.

Systematic Versus Diverse Problems

The problems and tasks posed to students can vary in systematic ways or in more diverse ways, as they do in life. For example, in mathematics one can give students a whole series of distance, rate, and time problems to solve, or one can have a mixture of many different kinds of problems.

One cost of giving students problems that vary systematically is that they will learn ad hoc strategies for solving the problems, which do not apply in other settings. Another is that they will not learn to figure out when a particular solution method or strategy is appropriate. The benefit of systematic variation is that induction is much easier and so learning is much more efficient. Schoenfeld's (1985) strategy in teaching problem solving is to start with systematic variation and move to more and more diverse problems.

Simple Versus Complex Tasks

There has been a tendency in education to simplify problems and tasks, so that all students can succeed with them. For example, we give students *Dick and Jane* to read rather than books like *The Hobbit*. The cost of simplification is oversimplification for many students: the tasks often become boring and meaningless. The benefits of simplification are that more students are likely to succeed, and it is possible to focus on important prerequisites.

In general, one wants to proceed from the simple to the complex, but ideally one should start at the optimum complexity for each student. This may mean doing some simple inquiry or assessment beforehand to determine where to start. Scaffolding (Palincsar & Brown, 1984) is designed to get students through more complex tasks with just as much support as they need, but no more.

Teaching Methods

There is a set of teaching methods associated with "cognitive apprenticeship" (Collins, 1991; Collins & Brown, 1988; Collins, Brown, & Newman, 1989) that have both advantages and disadvantages. The methods I will focus on are modeling, scaffolding, coaching, articulation, and reflection. These are discussed in more detail in the earlier papers.

Modeling

There are two kinds of modeling that are critical to consider in the design of learning environments (Collins, 1991): (1) modeling of the physical process underlying phenomena we want students to understand; and (2) modeling the thought processes underlying expert performance. For example, in the Quest system (White & Fredericksen, 1990), the system can model both how electricity flows in different circuits, and how an expert troubleshooter would locate a fault in different circuits.

The costs of modeling are that it is a passive activity and often boring for students. The benefits are that they can see normally invisible processes, and they can begin to integrate what happens with why it happens. Modeling is potentially very valuable, but it seems best to model early in the learning process and involve the learner as much as possible.

Scaffolding

Scaffolding is the support given to students as they carry out a task (Collins, Brown, & Newman, 1989; Palincsar & Brown, 1984). It can come in many different forms; for example, the short skis that enable people to learn to ski much faster (Burton, Brown, & Fisher, 1984), or the cue cards that Bereiter and Scardamalia (1987) give students to prompt them as they plan to write, the hints that Palincsar and Brown (1984) and Lesgold, Lajoie, Logan, and Eggan's (1991) Sherlock system provide students as they carry out a task.

The cost of scaffolding is that it is a crutch that students know they can fall back on, and so they may become dependent on it. The benefits of scaffolding are that it helps students to accomplish difficult tasks, providing focused help at critical times and only as much help as needed. It is, in fact, easier in designing learning environments to provide scaffolding than to provide the kind of coaching described next. Ideally, the scaffolding would be faded as students become more expert.

Coaching

Coaching involves a whole range of activities: choosing tasks, modeling how to do them, providing hints and scaffolding, diagnosing problems and giving feedback, challenging and offering encouragement, and structuring the way to do things. For example, Heath (1991) describes how a Little League baseball coach gets students to view mistakes as learning experiences, and Lepper, Aspinwall, Mumme, and Chabay (1988) describe how math tutors challenge students to get them to try difficult problems and not be afraid of failing. The most elaborate computer coach to date is the coach for the game "How the West Was Won," built by Burton and Brown (1982). The coach diagnoses the patterns of play the student is following, and then makes suggestions at opportune moments as to how the student might improve his or her game.

The costs of coaching have to do with the dangers of misdiagnosis, which is likely with computer coaches because of their limited bandwidth for viewing student behavior. To the degree that the diagnosis is shallow, as in the Anderson, Boyle, and Reiser (1985) tutors, then the likelihood of misdiagnosis decreases. The benefits of coaching are similar to those for scaffolding: coaching provides focused help at critical times and only as much help as needed. In the best cases, it can provide new ways of seeing what you are doing, which can help students out of ruts. Ideally, coaching, like scaffolding, should fade as students become more expert. But both computer and human coaching is very expensive to provide, and so it must have high payoffs to be worth the cost.

Articulation

Teachers have a variety of methods for getting students to articulate their ideas and thinking processes. For example, Bereiter and Scardamalia (1987) have students describe their thinking processes while planning an essay. Schoenfeld (1985) has students work in groups to solve difficult math problems, so that they are forced to articulate their thinking to each other. Inquiry teachers (Collins & Stevens, 1983) pose problems and questions for students to get them to articulate and refine their theories. As Brown (1985) has pointed out, programs like Robot Odyssey and Truckin force students to articulate their theories in order to construct robot agents to carry out their plans. These kinds of articulation help students formulate their ideas in a way that makes them available on other occasions.

The cost of articulation is that students may learn to talk a good game without really understanding. Also, emphasis on articulation discriminates against the less articulate, who might be able to do tasks perfectly well without any articulation. One benefit of articulation is that it helps make people's tacit knowledge explicit so that it is more available. Another benefit is that articulation allows people to see how other people think about the same problem. Making knowledge more available through articulation fosters transfer of th-· knowledge to new situations.

Reflection

Reflection involves looking back over one's performance on a task and comparing it to other people's performances, both good and bad, on similar tasks. This exploits the method of perceptual learning (Bransford, Franks, Vye, & Sherwood, 1989). For example, one can use reflective tape to mark critical parts of an athlete's body and videotape his or her performance in swinging a racket or throwing a javelin. Then it is possible to compare how his or her body moves during more and less successful performances, and how he or she moves compared to other athletes. This is what Collins and Brown (1988) call an abstracted replay. Another form of reflection is possible in Algebraland (Brown, 1985) or the Geometry Tutor (Anderson, Boyle, & Reiser, 1985) where the system keeps a record of all the student moves in solving an algebra equation or developing a geometry proof. These reifications of the problem-solving process allow similar kinds of reflection.

The costs of reflection are that students often find it tedious to have to look back at their performance, and usually do not have the patience to try to improve their performance. Most students just want to do an activity and then move on to other activities. The benefits of reflection are that students have a chance to see processes for the first time, much like their first exposure to a mirror, and to compare their ways of doing things to other people's ways. Because they can see themselves from a new angle, students begin to develop new ways of seeing and talking about what they do. I particularly recommend the kinds of abstracted replays and reifications described above (Collins & Brown, 1988) and the cycle of performing, reflecting, and re-performing embodied in Arts Propel (Gardner, 1990; Wolf. 1989).

Conclusion

These are my candidate set of issues that designers should be concerned about, omitting issues about the knowledge learned (Collins, Brown, & Newman 1989) and the social settings in which learning occurs (Collins, Greeno, & Resnick, in press) that I address elsewhere. By taking a cost-benefit approach to these issues, there is a chance that designers will be able to minimize the costs and maximize the benefits of any design decisions. ✧

References

Anderson, J. R., Boyle, C. F., & Reiser, B. J. (1985). Intelligent tutoring systems. *Science, 228*, 456-468.

Benezet, L. P. (1935). The teaching of arithmetic: The story of an experiment. *Journal of the National Education Association.*

Bransford, J. D., Franks, J. J., Vye, N. J., & Sherwood, R. D. (1989). New approaches to instruction: Because wisdom can't be told. In S. Vosniadou & A. Ortony (Eds.), *Similarity and analogical reasoning* (pp. 470-497). New York: Cambridge University Press.

Brown, A. L. (1992). *A community of learners.* Paper presented at the meeting of the American Educational Research Association, San Francisco.

Brown, J. S. (1985). Idea-amplifiers: New kinds of electronic learning. *Educational Horizons, 63*, 108-112.

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher, 18*(1), 32-42.

Burton, R., Brown, J. S., & Fisher, G. (1984). Skiing as a model of instruction. In B. Rogoff & J. Lave (Eds.), *Everyday cognition: Its developmental and social context* (pp. 139-150). Cambridge: Harvard University Press.

Burton, R. R., & Brown, J. S. (1982). An investigation of computer coaching for informal learning activities. In D. Sleeman & J.S . Brown (Eds.), *Intelligent tutoring systems* (pp. 79-98). New York: Academic Press.

Carver, S. M. (1990). *Integrating interactive technologies into classrooms: The Discover Rochester project.* Paper presented at the meeting of the American Educational Research Association, Boston.

Collins, A. (1991). Cognitive apprenticeship and instructional technology. In L. Idol & B. F. Jones (Eds.), *Educational values and cognitive instruction: Implications for reform.* (pp. 119-136). Hillsdale, NJ: Erlbaum.

Collins, A. (1990). Reformulating testing to measure learning and thinking. In N. Frederiksen, R. Glaser, A. Lesgold, & M. Shafto (Eds.), *Diagnostic monitoring of skills and knowledge acquisition* (pp. 325-350). Hillsdale, NJ: Erlbaum.

Collins, A., & Brown, J. S. (1988). The computer as a tool for learning through reflection. In H. Mandl & A. Lesgold (Eds.), *Learning issues for intelligent tutoring systems.* New York: Springer.

Collins, A., Brown, J. S., & Newman, S. E. (1989). Cognitive apprenticeship: Teaching the crafts of reading, writing, and mathematics. In L. B. Resnick (Ed.), *Knowing, learning, and instruction: Essays in honor of Robert Glaser* (pp. 453-494). Hillsdale, NJ: Erlbaum.

Collins, A., Greeno, J. G., & Resnick, L. B. (in press). Learning environments. In *International encyclopedia of education* (2nd ed.). Oxford, UK: Pergamon.

Collins, A., Hawkins, J., & Carver, S. M. (1991). A cognitive apprenticeship for disadvantaged students. In B. Means, C. Chelemer, & M. S. Knapp (Eds.), *Teaching advanced skills to at-risk students* (pp. 216-243). San Francisco: Jossey-Bass.

Collins, A., & Stevens, A. L. (1982). Goals and strategies of inquiry teachers. In R. Glaser (Ed.), *Advances in instructional psychology* (Vol. 2) (pp. 65-119). Hillsdale, NJ: Erlbaum.

Collins, A., & Stevens, A. L. (1983). A cognitive theory of interactive teaching. In C. M. Reigeluth (Ed.), *Instructional design theories and models: An overview* (pp. 247-278). Hillsdale, NJ: Erlbaum.

Cuban, L. (1984). *How teachers taught.* New York: Longman.

Frederiksen, J. R., & White, B. Y. (1990). Intelligent tutors as intelligent testers. In N. Frederiksen, R. Glaser, A. Lesgold, & M. Shafto (Eds.), *Diagnostic monitoring of skill and knowledge acquisition* (pp. 1-25). Hillsdale, NJ: Erlbaum.

Harel, I. (1990). Children as software designers: A constructionist approach for learning mathematics. *The Journal of Mathematical Behavior, 9*(1), 3-93.

Hirsch, E. D., Jr. (1987). *Cultural literacy: What every American needs to know.* Boston: Houghton Mifflin.

Lampert, M. (1986). Knowing, doing, and teaching multiplication. *Cognition and Instruction, 3*, 305-342.

Lepper, M. R., Aspinwall, L., Mumme, D., & Chabray, R. W. (1988). Self-perception and social perception processes in tutoring: Subtle social control strategies of expert tutors. *Self-inference processes: The Ontario Symposium in Social Psychology.*

Lesgold, A., Lajoie, S., Logan, D., & Eggan, G. (1990). Applying cognitive task analysis and research methods to assessment. In N. Frederiksen, R. Glaser, A. Lesgold, & M. Shafto (Eds.), *Diagnostic monitoring of skills and knowledge acquisition* (pp. 325-350). Hillsdale, NJ: Erlbaum.

Palincsar, A. S., & Brown, A. L. (1984). Reciprocal teaching of comprehension-fostering and monitoring activities. *Cognition and Instruction, 1*, 117-175.

Resnick, L. B., Bill, V. L., Lesgold, S. B., & Leer, M. N. (1991). Thinking in arithmetic class. In B. Means, C. Chelemer, & M.S. Knapp (Eds.), *Teaching advanced skills to at-risk students* (pp. 27-53). San Francisco: Jossey-Bass.

Schoenfeld, A. J. (1985). *Mathematical problem solving.* New York: Academic Press.

Stevens, A., & Roberts, B. (1983). Quantitative and qualitative simulation in computer-based training. *Journal of Computer-Based Instruction, 10*, 16-19.

Stigler, J. W., & Perry, M. (1988). Mathematics learning in Japanese, Chinese, and American classrooms. In G. Saxe & M. Gearhart (Eds.), *Children's mathematics.* San Francisco: Jossey-Bass.

White, B. Y., & Frederiksen, J. (1990). Causal model progressions as a foundation for intelligent learning environments. *Artificial Intelligence, 24*, 99-157.

Wiggins, G. (1989, May). A true test: Toward more authentic and equitable assessment. *Phi Delta Kappan*, 703-713.

Wolf, D. P. (1987, December). Opening up assessment. *Educational Leadership*, 24-29.