DOCUMENT RESUME

ED 407 925 IR 018 315

AUTHOR	Reif, Frederick; Scott, Lisa A.
TITLE	Students and Computers Coaching Each Other: A Method for Teaching Important Thinking Skills.
SPONS AGENCY	National Science Foundation, Arlington, VA.
PUB DATE	Mar 97
NOTE	17p.; Paper presented at the Annual Meeting of the American Educational Research Association (Chicago, IL, March 24-28, 1997).
CONTRACT	MDR-9150008
PUB TYPE	Reports - Research (143)
EDRS PRICE	MF01/PC01 Plus Postage.
DESCRIPTORS	Academic Achievement; *Autoinstructional Aids; Cognitive Processes; *Computer Assisted Instruction; Computer Managed Instruction; Higher Education; Instructional Design; Physics; Pilot Projects; Problem Solving; *Programmed Instructional Materials; Science Education; *Thinking Skills; User Satisfaction (Information)
IDENTIFIERS	*Automated Tutoring; Coaching; Role Reversal

ABSTRACT

The acquisition of factual knowledge is increasingly insufficient to prepare students to cope in this complex and rapidly changing world. Students need to learn effective ways of thinking so they can use their acquired knowledge flexibly, solve diverse problems, and become good independent learners. Two pervasive educational problems limit the possible efficacy of any instruction: (1) lack of individual guidance and feedback; and (2) deficiencies of basic cognitive functions. A computer-implemented reciprocal-teaching strategy can help students learn important cognitive abilities. A prototype computer tutorial was designed to teach college students Newton's second law of motion, a principle taught in every basic physics course and one with which students often have difficulty. In the basic implementation tutorials, PAL (the computer used as Personal Assistant for Learning) plays the role of a coach who makes decisions according to the methods suggested by the student, and then assesses and corrects the students' implementations. In the basic coaching tutorials, the roles of implementer and coach are reversed, with the student practicing how to make appropriate decisions and assessing PAL's implementation. The tutorial programs were tested in a pilot experiment in an introductory physics course for college science majors. Student volunteers (n=45) were divided into a PAL group, a tutoring group, and a control group for a homework assignment dealing with the application of Newton's laws. Students in the PAL and tutoring groups performed appreciably better than students in the control group. Students had very positive reactions to the PAL tutorials, and seem to have acquired a more explicit knowledge about relevant thinking processes from using the tutorials. Implications are discussed. (Contains 14 references.) (SWC)

Paper presented at the March 1997 Chicago meeting of the American Educational Research Association

Students and computers coaching each other: A method for teaching important thinking skills

Frederick Reif* and Lisa A. Scott†

Center for Innovation in Learning
Carnegie Mellon University
Pittsburgh, PA 15213

1. Introduction

Educational challenge of our technological age. The mere acquisition of factual knowledge is increasingly insufficient to prepare students to cope with our complex and rapidly changing world. Instead, they need to learn effective ways of thinking so that they can use their acquired knowledge flexibly, solve diverse problems, and become good independent learners.

Hence we are faced with a major educational challenge. It is much more difficult to teach effective ways of thinking than the memorization of various kinds of factual knowledge. Indeed, these difficulties are often all too evident. For example, recent investigations show that many students (even when they receive good grades) emerge from basic science courses with gross misconceptions, with prescientific notions, and with nominal knowledge that they cannot properly use [1-4].

Addressing the challenge. Efforts aiming to transcend the acquisition of factual knowledge must identify and teach some important cognitive abilities [5]. (a) For example, much attention must be paid to *procedural knowledge*. Thus it is necessary to teach explicitly the procedural knowledge needed to properly interpret concepts, principles, and other declarative knowledge. (Indeed, any factual statement is meaningless unless one knows methods specifying how one can determine whether it is true or false.) It is also necessary to teach useful methods for analyzing problems and for making the decisions needed to construct their solutions. (b) Similarly, one must identify and teach *forms of knowledge* facilitating effective use (e.g., hierarchical knowledge organizations, and complementary qualitative and quantitative descriptions in various symbolic representations).

Successes and limitations of past work. During the last several years one of us (FR) has been engaged in work aiming to investigate and teach such cognitive abilities [4-8]. This work has shown that some of these important abilities can be explicitly taught [9], that they can be addressed in practical instructional materials [10], and that they lead to substantial improvements of student performance in actual courses [5].

However, this work has also revealed some profound educational problems that limit the possible efficacy of any instruction, no matter how well it might be designed. The aim of this paper is to point out two of these pervasive problems and to describe work showing how they might be overcome.

2. Pervasive educational problems

2.1 Lack of individual guidance and feedback

Learning requirements. Effective learning requires active thinking and practice by the learner. But the learning activities must also be of the right kind. For example, hours spent practicing the wrong things can easily be ineffectual or counterproductive, leading to harmful results or to bad habits that are difficult to break.

Instructional efforts should, therefore, be based on a good understanding of the learning processes needed to attain proficient performance. However, even such a perfect understanding is *not* sufficient. One must also ensure that students actually engage in these learning processes — otherwise no effective learning would occur. (The situation is analogous to that in medicine. Even if one understands perfectly a disease and has developed pills guaranteeing its cure, people's health would not improve if they don't take the pills according to the recommended regimen.)

A useful way of ensuring that students engage in effective learning processes is to provide them with good individual guidance and feedback. Indeed, such individual guidance and feedback are commonly provided by coaches or teachers who aim to produce good athletes or fine musical performers.

Prevailing instructional deficiencies. However, students receive ordinarily very little individual guidance and feedback in our educational system where they spend most of their time in large classes or studying without supervision. Under these conditions *it is nearly impossible to ensure that students engage in effective learning processes, even if these processes are well known.* Hence there exists a serious impediment limiting the possible efficacy achievable even by carefully designed instructional programs.

For example, textbooks, lectures, and recitation sections may all discuss and demonstrate good problem-solving methods. But when students do their homeworks under unsupervised conditions, many revert to preexisting habits and try to solve problems by haphazardly grabbing miscellaneous equations. Unfortunately, hours of such homework "practice" are likely to do them more harm than good. On the other hand, an hour of individual tutorial help may sometimes help a student much more than all the lectures, readings, and homework assignments in a course.

Suggested remedy: Use of computers. How could one provide effective individual guidance and feedback to large numbers of students in our educational system? It is clearly impossible to provide every student with a good private tutor. But modern computers (and associated electronic media) are now increasingly available to many students. Properly designed computer programs could thus help to ensure that every student engages in effective learning processes. The guidance and feedback provided by such computer programs might well be less good than those ideally available from human tutors. However, they might still be much better than what most students currently receive.

2.2 Deficiencies of basic cognitive functions

Learning requirements. Good performance of any task requires the following essential cognitive functions: (a) Making appropriate decisions, (b) implementing these, and (c) assessing whether performance has been satisfactory.

When tasks are highly familiar (e.g., typing one's name) these functions are often carried out without conscious awareness. But in the case of more complex or unfamiliar tasks, these functions need to be carried out quite deliberately. The learning of problem solving or other complex tasks requires, therefore, also learning the basic abilities of properly deciding, implementing, and assessing.

Deficiencies of students' cognitive functions. Observations of students suggest that many of their difficulties are traceable to deficiencies in these basic cognitive functions. Although students are usually most concerned with implementing various actions, their implementations are often faulty. Even more frequently, students fail to make appropriate decisions or to assess what they have done. (As Goethe once said, "acting is easy, thinking is hard".)

For example, many students don't perceive the need to assess carefully what they have done, or sometimes do not know *how* to assess effectively their performance. As a result, students often fail to learn from their mistakes. Hence their errors or misconceptions may persist for long times.

Deficiencies of appropriate decision making are even more commonly observed. (a) Such deficiencies sometimes cause students not to invoke useful knowledge that they do possess. (b) They often cause a lack of reliable sequence control in implementing methods, with the result that steps get omitted or invoked in the wrong order. (As a result, one commonly observes among students "procedures that don't proceed".) (c) Lastly, decision-making deficiencies are particularly fatal in problem solving where judicious decisions are of central importance.

Suggested remedy: A reciprocal-teaching strategy. The preceding deficiencies led us to devise the following instructional strategy explicitly designed to improve students' basic abilities of deciding, implementing, and assessing.

This strategy, illustrated in Figure 1, involves the following two distinct modes of interaction between a student S and a tutor T. (The modes are named in accordance with the role played by the student.)

(1) *Implementing mode.* In this mode (a) the tutor decides what to do and gives corresponding directions, (b) the student implements these, and (c) the tutor assesses and corrects. (In this mode the student thus practices implementing while the tutor acts as a coach.)

(2) *Coaching mode.* In this mode, the roles are reversed. Thus (a) the student decides what to do and gives corresponding directions, (b) the tutor implements these (but may deliberately make mistakes reflecting those commonly made by many students), and (c) the student assesses and corrects. (In this mode the student practices decision making and assessing, i.e., the student acts somewhat like a coach.)

During the instruction, the student and tutor repeatedly change roles, alternating between these two modes of interaction. This instructional strategy becomes then a "reciprocal teaching" strategy.

Theoretical advantages of this reciprocal-teaching strategy. Cognitive considerations suggest that this strategy should be highly effective for the following reasons:

(1) The instruction is highly interactive and the student is always kept actively engaged.

(2) The functions of deciding, implementing, and assessing are made highly explicit.

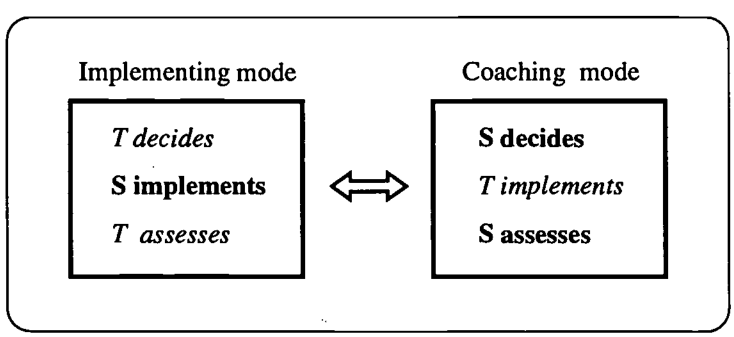

Figure 1. Reciprocal-teaching strategy with alternating modes of interaction between a student S and a tutor T.

(3) The student practices these functions separately, but always in the full context of an entire meaningful task. (Separate practice allows focused attention and reduces cognitive load that may transcend learning capacities. But maintaining the entire task context makes apparent all potentially useful cues — and provides practice in contexts in which the student will ultimately need to use the cognitive functions to be learned.)

(4) Since the implementing and coaching roles alternate, the tutor repeatedly models good performance of a function before the student, in turn, needs to perform this function.

(5) The tutor repeatedly monitors how well the student performs at any stage — and can then provide appropriate feedback and adjust the instruction accordingly.

(6) The tutor can progressively reduce the level of assistance provided to the student. Thus the student can gradually learn more independent and joint performance of the functions of decision making, implementing, and assessing.

Empirical evidence of efficacy. We performed some pilot experiments in which one of us (LAS) played the role of tutor in applying this reciprocal-teaching strategy to teach college students some physics concepts and principles. The results were quite promising. Not only did the students learn these concepts and principles, but they also made more articulate decisions, assessed their work more carefully, and did these things more spontaneously.

The reciprocal-teaching strategy was first introduced by Palincsar and Brown [11,12] in a very different context and with very different aims (to teach reading-comprehension skills to middle-school children). The reading strategy taught by them proved highly effective, raising children's reading-comprehension skills from about 30% to 80%. Although their context was quite different, some of the efficacy of their reciprocal-teaching reading strategy can also be attributed to the same advantages listed above.

3. Proposed instructional design

The preceding considerations suggest that the identified instructional problems could be overcome (and effective thinking skills could be more effectively taught) by instructional design incorporating the following main guidelines:

Cognitive analysis. The instruction needs to be based upon an adequate understanding of the thought and learning processes leading to good performance.

Use of the proposed reciprocal-teaching strategy. By embedding instruction in this reciprocal-teaching strategy, one can help ensure that the basic cognitive functions needed for good performance (i.e., appropriately deciding, implementing, and assessing) are learned and carried out.

Computers used to implement reciprocal teaching. The role of the tutor T in the proposed reciprocal-teaching strategy of Figure 1 can also be played by a properly programmed computer rather than by a human tutor. There are two resulting advantages: (a) The reciprocal-teaching strategy can then be more readily implemented without the (largely impractical) need to rely on human tutors. (b) Such computers can then also provide many students with prompt well-designed individual guidance and feedback of the kind commonly lacking in most courses.

Simple instructional implementations. It is desirable to keep the implementation of the preceding instructional guidelines as simple as possible because they could then be more readily realized in practice. (In particular, they could then be more widely produced by faculty members or subject-matter experts without much programming expertise.) Indeed, even without resorting to the techniques of artificial intelligence, well-designed computer programs could play the role of tutors that provide students with much better instruction than many currently receive. To indicate that a computer running such tutorial programs may not be endowed with the natural or artificial intelligence of a real tutor, we call it a "PAL" (a Personal Assistant for Learning).

4. Computer tutorials implementing the design

To explore how the preceding instructional design might actually be implemented in practice, we constructed a set of prototype computer tutorials exemplifying the preceding guidelines. The following description of these prototypes illustrates more concretely the proposed approach and demonstrates its feasibility.

4.1 Choice of prototypical task domain

The proper interpretation and application of scientific principles is a demanding task difficult for many students. Accordingly we wanted to explore how our approach might be used to teach such principles more effectively. In particular, we chose to focus our attention on a fundamentally important principle of mechanics, Newton's second law of motion $m\vec{a} = \vec{F}_{tot}$, which relates the acceleration $\vec{a}$ of any object to the total force $\vec{F}_{tot}$ acting on it [13].

This principle is taught in every basic physics course. The thinking skills necessary to interpret and apply this principle are typical of those needed in many scientific or engineering fields. Furthermore, despite its seeming simplicity, the proper application of Newton's law causes students many difficulties and often becomes a major learning hurdle for them.

4.2. Cognitive task analysis

Any principle expresses a relationship between some concepts. The interpretation and application of a principle thus requires the following kinds of procedural knowledge: (a) A *concept-specification method* specifying how to describe the related concepts in any specific instance, and (b) a *relation-specification method* specifying how to express the relationship between these concepts in this instance.

In particular, Newton's law $m\vec{a} = \vec{F}_{tot}$ expresses a relationship between the properties of any "system" (the mass of the object of interest and the acceleration describing its motion) and its interactions with other objects. (These interactions are described by the total force on the system, i.e., by the vector sum of the forces exerted on it by all other objects.) Correspondingly, the application of Newton's law requires procedural knowledge that can be specified by the following two methods:

(a) *Concept-specification method.* This method (outlined in Figure 2a) describes the motion and interactions of the system in the convenient form of a "system diagram". It does this by identifying all available information about the mass of the system, about its motion (velocity and acceleration), and about the forces describing all its interactions. (The method separately identifies long-range interactions, like gravity, that are appreciable even if objects are far apart — and contact interactions that are appreciable only if objects are so close as to touch each other. Furthermore, it always identifies the interacting object before specifying the corresponding force produced by it.) Finally, the method specifies how vectors can be usefully decomposed into component vectors along convenient directions.

(b) *Relation-specification method.* This method (outlined in Figure 2b) specifies how Newton's law is used to express the relationship between the motion and interactions of the system. (As indicated in this figure, this relationship is most usefully expressed in terms of the numerical components of the related quantities along mutually perpendicular directions.)

The preceding two methods, based on a task analysis, are significantly more specific and detailed than those commonly mentioned in textbooks dealing with Newton's law. (Of course, they also require prerequisite knowledge about the properties of velocity and acceleration, about various kinds of forces, and about vector components.)

Our prototype tutorials, described in the following paragraphs, were designed to teach systematic application of the preceding two methods to deal flexibly with various situations requiring application of Newton's law.

4.3 Description of basic tutorials

Basic implementation tutorials. These tutorials are designed to teach students the basic abilities needed to implement application of Newton's law. Accordingly, PAL (the computer used as Personal Assistant for Learning) plays here the role of a coach who makes decisions according to the suggested methods — and then assesses and corrects the students' implementations.

Each tutorial presents a specific mechanics problem. A simple tutorial, dealing with a single system of interest, consists of three sections. These successively aim to describe the motion and interactions of this system, to construct the equations expressing Newton's law, and to explore the qualitative implications of these results.

In the first section of such a tutorial, PAL explicitly displays the concept-specification method of Figure 2a (i.e., the method specifying how to construct a diagram describing a system's motion and interactions). PAL gives the student successive directions by following the steps of this method. The student implements each of these successive steps and PAL assesses whether the student's implementation

(a) *Concept specification*

> **Separate diagram of system**
> **Mass**
- **Motion** (> Velocity) (> Acceleration)
- **All forces on system**
  - Long-range forces (e.g., gravity)
    > Long-range interacting objects?
    > Long-range forces on system
  - Contact forces
    > Touching objects? (Label contacts)
    > Contact forces on system
- **Components** (> Directions?) (> Draw)

(b) *Relation specification*

> **Convenient perpendicular directions**
- **Apply the law along one of these directions**
  > Choose particular direction
  > Mass × (acceleration component)
  > Sum of all force components
- **Apply the law along the other direction**
  > Choose particular direction
  > Mass × (acceleration component)
  > Sum of all force components

Figure 2. Methods needed for applying Newton's law. (a) Method for specifying the concepts describing a system's motion and interactions. (b) Method for expressing Newton's law specifying the relationship between a system's motion and interactions.

is correct. If it is not, PAL provides hints or other feedback to help the student correct his or her work. If it is correct, PAL indicates the completed step by drawing a corresponding part of the diagram. In this way the entire correct diagram, describing the motion and interactions of the system, is progressively constructed on the computer screen. (Figure 3 shows a black-and-white illustration of such a multicolored screen.)

In the second section of the tutorial, PAL similarly displays the relation-specification method of Figure 2b (i.e., the method specifying how to construct the equations expressing Newton's law). As before, PAL gives the student successive directions following the steps of this method. To implement these steps, the student is asked to click on appropriate parts of the diagram to specify corresponding terms in an equation. (In this way, PAL tries to maintain a clear connection between the previously constructed diagram and the equation expressing Newton's law.) If the student makes a mistake, PAL again provides hints or feedback so that the student can correct it. In this way, the student constructs the relevant algebraic equations expressing Newton's law for the system. (Figure 4 shows an illustration.)

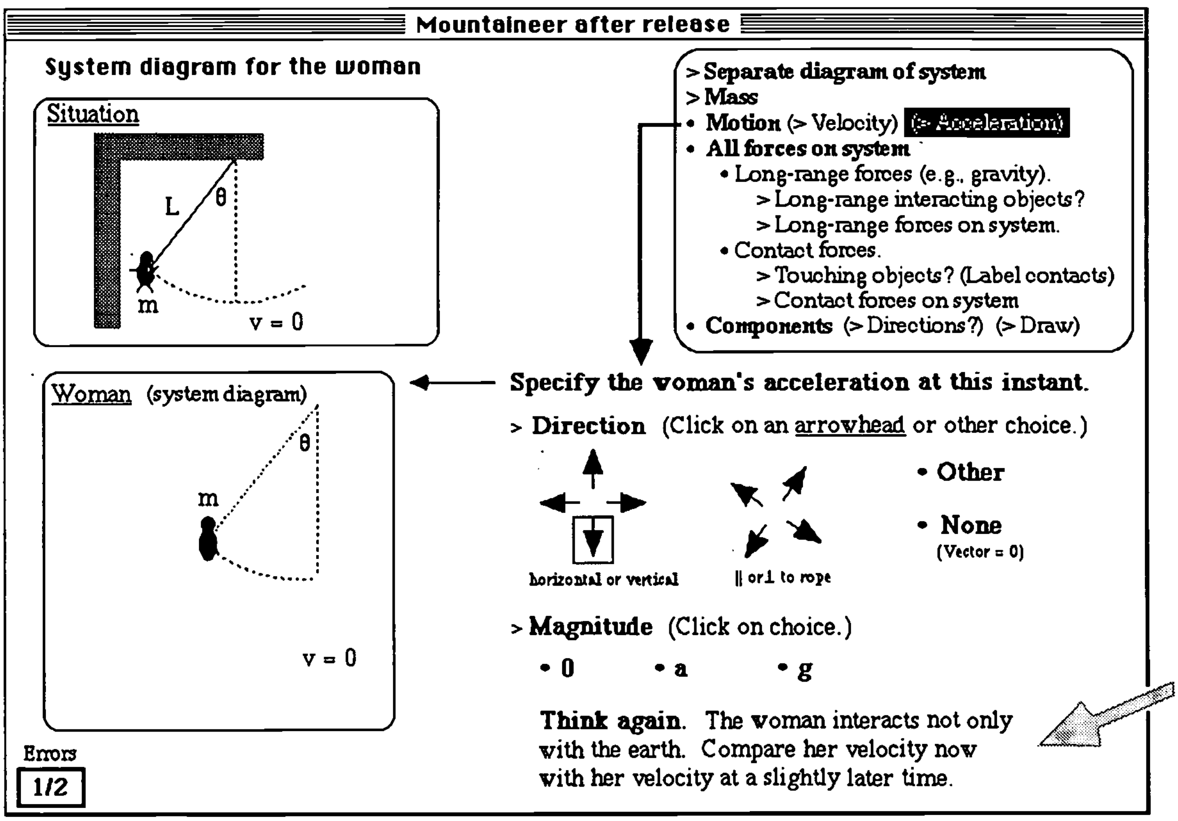

Figure 3. A computer screen from an implementation tutorial. (The student, asked to construct a system diagram, has just made a mistake in specifying the direction of the acceleration. Hence PAL provides the feedback message indicated by the gray arrow.)

BEST COPY AVAILABLE

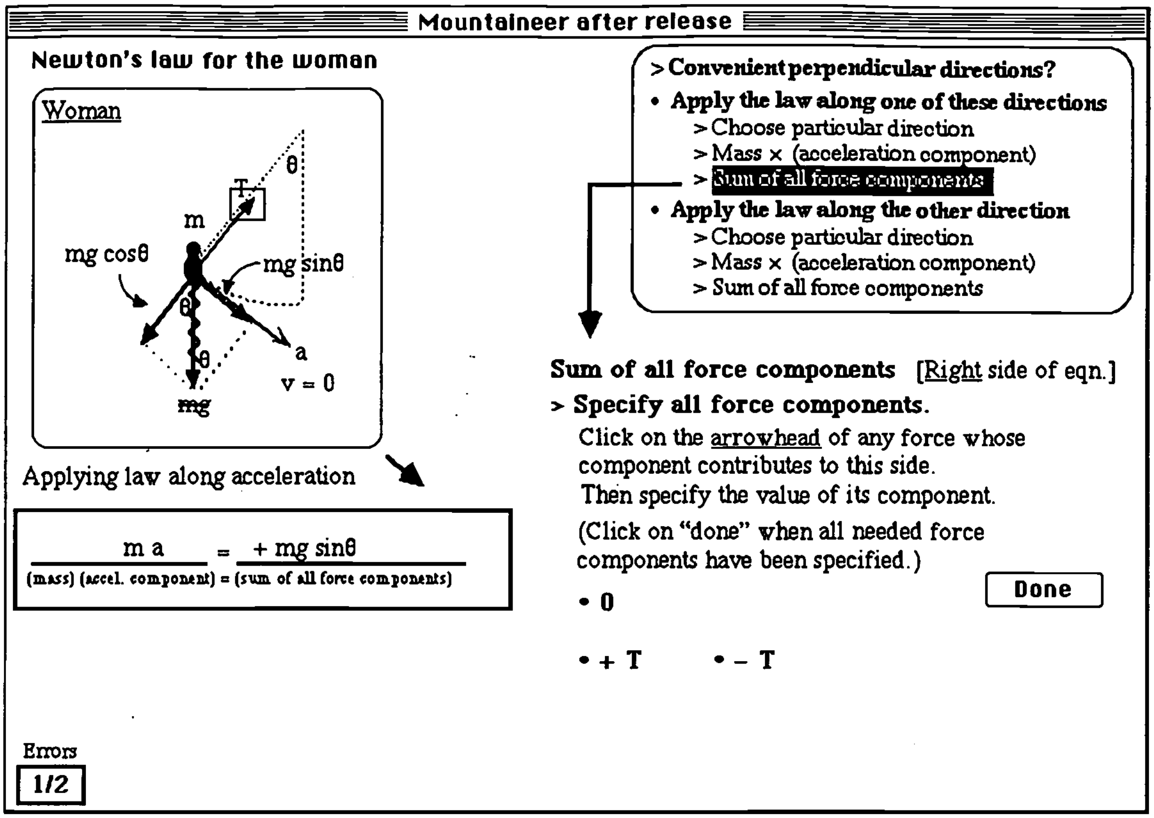

Figure 4. Another computer screen from an implementation tutorial. (The student, asked to construct the equations expressing Newton's law, has clicked on the force T in the diagram and is now asked to specify its component.)

In the third section of the tutorial, PAL asks questions requiring the student to explore some of the qualitative implications of his or her previously constructed equations. (For example, PAL may ask whether some quantity of interest is larger or smaller than some other quantity, or how such a quantity changes when some other quantity increases or decreases.) In this way, PAL tries to ensure that the student does not consider equations as mere symbolic expressions, but can interpret them both quantitatively and qualitatively.

Basic coaching tutorials. In these tutorials, the roles of implementer and coach are reversed. Thus the student now acts more like a coach, practicing how to make appropriate decisions and how to assess PAL's implementations of them.

Each tutorial again presents a specific problem. In the first section of the tutorial, PAL displays, *in randomized order*, the steps of the concept-specification method of Figure 2a. PAL then repeatedly asks the student what it (PAL) should do next to describe a particular system. To decide what should be done and direct PAL to do so, the student must then select an appropriate step in the proper order. PAL dutifully implements this step, but may make mistakes. (Indeed, PAL deliberately makes mistakes reflecting common student misconceptions or errors.) After implementing a step, PAL always reminds the student to warn it if there are any errors. (If the student does *not* catch a mistake and asks PAL to proceed, PAL expresses misgivings and asks the student to check more carefully.) Whenever the student detects a mistake, PAL asks the student to identify the nature of the mistake and to correct it. PAL thus gradually manages to draw a correct diagram on the computer screen. (Figure 5 shows an illustration.)

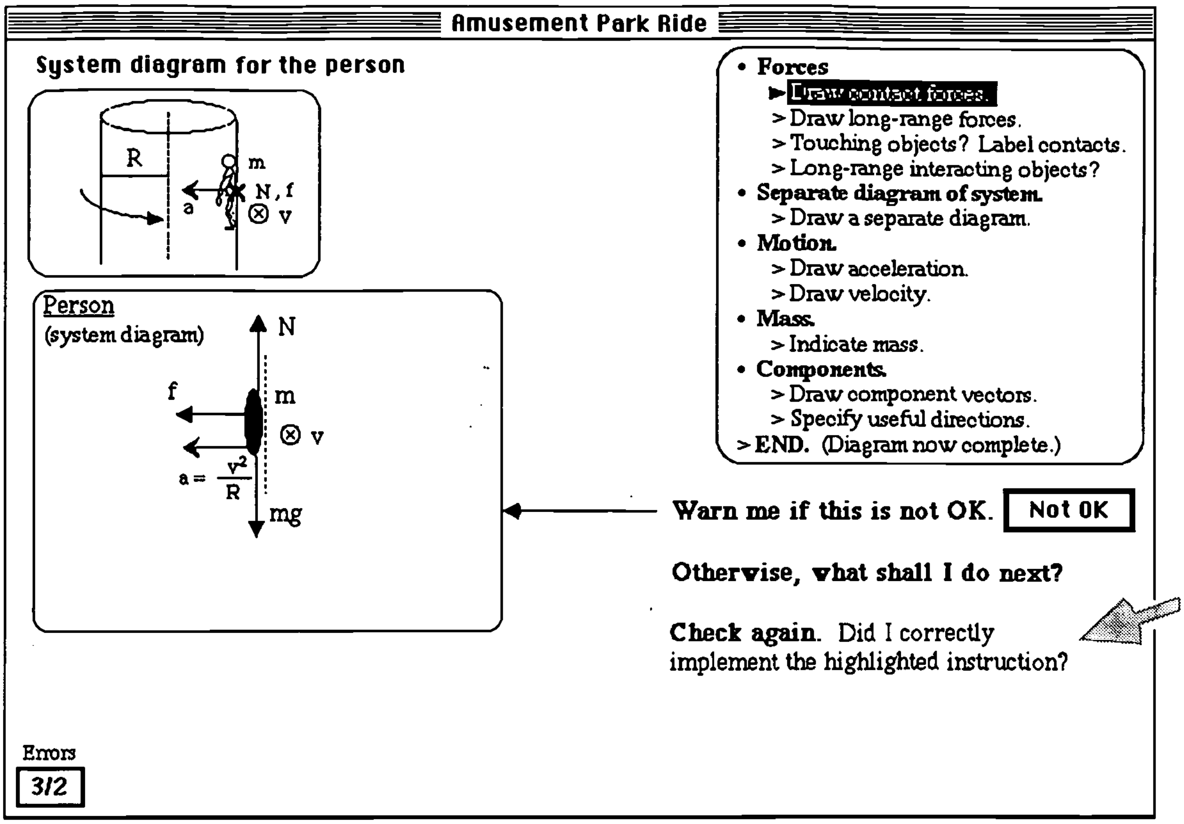

Figure 5. A computer screen from a coaching tutorial. (The student has just agreed to wrong contact forces drawn by PAL. The message, indicated by the gray arrow, therefore asks the student to check whether PAL has indeed correctly implemented the indicated step of the method.)

The second section of the tutorial is designed similarly, except that it deals with the method of Figure 2b for specifying the equations expressing Newton's law. Thus PAL again implements the student's directions to construct appropriate equations, but may make mistakes. It is then up to the student to identify and correct all such mistakes.

Lastly, in the third section of the tutorial, PAL states some qualitative implications which the student again may need to correct.

Alternating use of these tutorials. In accordance with the reciprocal-teaching strategy, the preceding two types of tutorials are used alternately. In one type of tutorial the student can then observe how PAL decides, implements, or assesses. In the other type of tutorial, the student himself or herself then practices deciding, implementing, or assessing.

4.4 Description of more advanced tutorials

More advanced tutorials aim to reduce the guidance to students so that they may learn to work more independently under conditions closer to those faced in their courses and future professional lives.

More advanced implementation tutorials. These tutorials require students to work on paper without detailed step-by-step guidance from PAL. They also try to convince students that their own haphazard ways of proceeding are often inadequate — and thus to motivate them to adopt the more systematic methods suggested by PAL.

An advanced implementation tutorial, like one of the previously described basic tutorials, consists of three sections (drawing a diagram describing the system, writing the equations expressing Newton's law, and examining their implications). However, the student is immediately presented with the challenge of doing an entire such section independently, *on paper*, without any step-by-step directions.

PAL then checks the student's performance by asking a set of questions carefully designed to detect deficiencies in the student's work. (Figure 6 illustrates such a checking question.) If all the student's answers are satisfactory, the student goes on to the next section. Otherwise, PAL warns the student that something is wrong, reminds him/her of the systematic method, and may provide a few diagnostic hints. If the student is still unable to revise his/her work so as to answer all checking questions correctly, PAL guides the student through the section step-by-step according to the suggested method (just as it did in a basic tutorial). In this way the student practices the method again and can diagnose the mistakes in his/her previous independent work. Finally, the student is presented with his/her previous answers to the checking questions so that the student can correct them appropriately.

More advanced coaching tutorials. In these tutorials PAL solves an entire problem, but occasionally pauses either (a) to ask the student to judge the correctness of its actions, or (b) to ask the student for advice or help. PAL again makes deliberately some mistakes reflecting commonly encountered errors or misconceptions. The student needs then to detect all such mistakes and must tell PAL how to correct them.

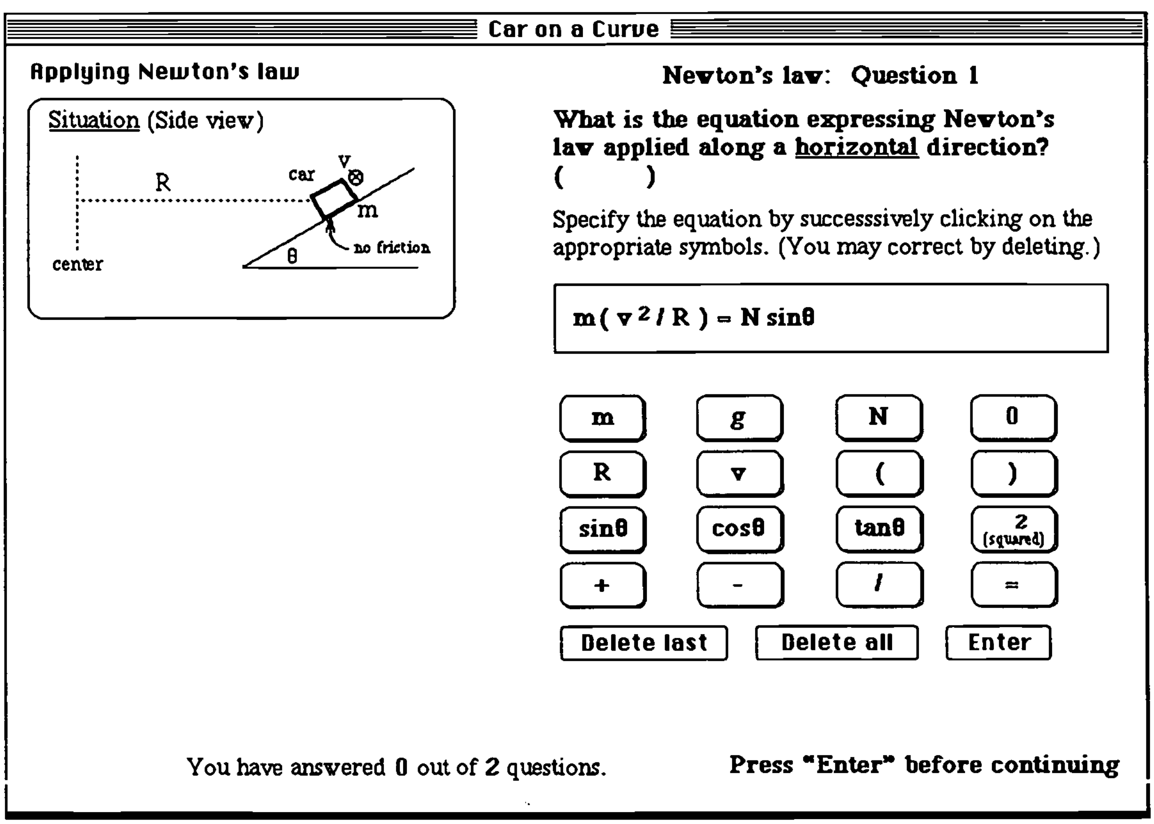

Figure 6. A computer screen from a more advanced implementation tutorial. (The student is here asked to check his/her work by entering the equation that he/she obtained by applying Newton's law.)

4.5 Implementation details

All the preceding tutorials were designed to run on Macintosh computers with color monitors. For the sake of simplicity, they were written in "Authorware", a programming language designed for instructional applications and commercially distributed by Macromedia, Inc.

5. Assessment of efficacy

We constructed about ten tutorial programs of the preceding kinds and tried them with individual students (as well as with some colleagues). These trials led to many pedagogical revisions as well as interface refinements.

Recently we were able to carry out a pilot experiment designed to test these tutorials in a more realistic classroom situation. The following paragraphs describe this pilot experiment and its results.

5.1 Design of the pilot experiment

Last fall (fall 1996) the introductory physics course for science majors at Carnegie Mellon University had an enrollment of about 240 students. A homework assignment dealing with the application of Newton's laws was scheduled to be given to students during the fifth week of that course. We took advantage of this opportunity to request permission of the instructor (Professor Gregg Franklin) to have some students in the course work on this assignment under somewhat modified conditions.

Accordingly, we recruited from the course about 75 student volunteers with the offer of providing some of them special help with the assignment for that week. (The nature of this special help was *not* specified.) From these volunteers, we selected 45 whom we divided into the following three equal groups selected to be of equivalent abilities (by matching their scores on two previous tests given in the course).

(1) *PAL group.* This group was to work on an equivalent assignment where most problems were in the form of PAL tutorials dealing with problems identical, or very similar, to those in the regular assignment. About six students at a time did this by coming, for several 90-minute work sessions, to a special room where computers had been set up for their use.

(2) *Tutoring group.* This group was to work on the assignment under conditions where they would receive individual help from very experienced human tutors (one of us or Professor Jill Larkin). About six students at a time did this by coming, for several 90-minute work sessions, to another special room where one or two of these tutors were available.

(3) *Control group.* This group was to work on the assignment under regular conditions (i.e., with access to the ordinary help accessible to all students from the teaching assistants in the course). The students in this group were told that we could not accommodate them. However, they were later used by us as a comparison group of equally motivated volunteers receiving no special treatments.

5.2 Implementation of the experiment

Students varied appreciably in the time they required to complete the assignment. (The average time was about 5.5 hours for the PAL group and somewhat less for the Tutoring group.)

Students in the PAL group were constantly and actively engaged with their computer tutorials and required very little outside assistance. Indeed, one person could easily supervise a work session of six or seven students, and yet be unoccupied most of the time. By contrast, at least two tutors were required to deal with an equally large work session from the Tutoring group in order to answer the students' questions and keep them from unproductive floundering.

5.3 Student performance data

A test, given to all the students in the class at the end of the week after the preceding assignment, provided data on how well students had learned to apply Newton's law. This "Newton test" consisted of two problems dealing with application of this law. The tests for all students were graded by the teaching assistants in the course. In addition, the tests for the students in our three selected groups were independently graded by us (with more detailed attention to the nature of the errors committed by the students).

Test scores. The gross test scores obtained by these two grading methods were nearly the same. They are most conveniently summarized by the box plots in Figure 7 which indicate the medians and quartiles for the students in the various groups.

Comparisons of performance on the Newton test. The data shown in Figure 7a lead to the following conclusions about the comparative performance of the three groups of students:

(1) The students in the PAL and Tutoring groups (receiving average scores of 76% and 84%) performed appreciably better than the students in the Control group (average score of 62%). Indeed, about half the students in the Control Group received scores below 65%, while almost none the students in the PAL and Tutoring Groups received scores below this amount.

(2) Compared to the students in the Control group, the students in the PAL and Tutoring groups also made appreciably fewer mistakes in identifying forces or applying Newton's law.

(3) The students receiving individual human tutoring performed somewhat better than those working with the computer tutorials. However, PAL tutorials (even if not improved beyond the present prototypes) could be quite effective and could be made readily available to large numbers of students. On the other

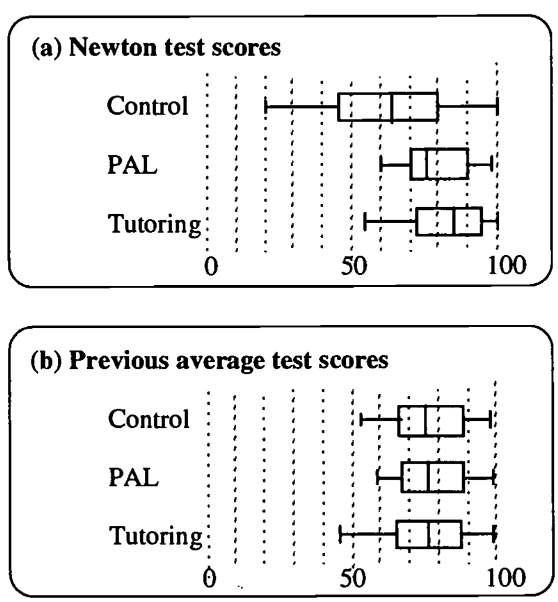

Figure 7. Test scores of the three groups of students. (The box plots indicate medians and quartiles.)

hand, it would be practically impossible to provide a significant number of students with many hours of expert tutoring help of the kind that the Tutoring group received in this pilot experiment.

Comparisons with performance on previous tests. It is also of interest to compare the students' performance on this Newton test with their performance on the two *prior* tests that they had taken in the physics course.

Figure 7b shows the average scores that the students had received on these two prior tests. These score distributions are nearly the same for the students in all groups (since the groups had been carefully selected to be equivalent).

Figure 7 indicates that the subsequent Newton test scores of the students in the PAL and Tutoring Groups are not very different from those on their prior tests. On the other hand, the subsequent Newton test scores of the students in the Control Group are much worse. Indeed, while only a quarter of these students received scores less than 65% on the prior tests, about half of these students received scores below this amount on the Newton test.

This result suggests a plausible interpretation. The proper application of Newton's law is for many students a difficult task, requiring proper interpretation of this law as well as integrated application of all previously acquired physics knowledge about vectors, motion, and various kinds of forces. The special help provided to students in the PAL and Tutoring groups apparently allowed them to face these complex task demands without undue difficulties. But, without such special help, many students in the Control group could not cope — with the result that their performance substantially deteriorated on a crucially important part of the course.

5.4 Student reactions

Questionnaire results. Student reactions to the PAL tutorials were very positive. For example, a questionnaire, given to students in the PAL group, asked the following question: "How useful were these computer tutorials in helping you learn to apply Newton's laws?". As indicated in Figure 8, almost all the students thought that they were very useful and none rated them less than useful.

Student interviews. To get more detailed information about students' reactions, we asked an outside person (the director of Carnegie-Mellon's Teaching Center) to interview a couple of representative students from each group. Her report, summarizing her interviews with these students, is revealing.

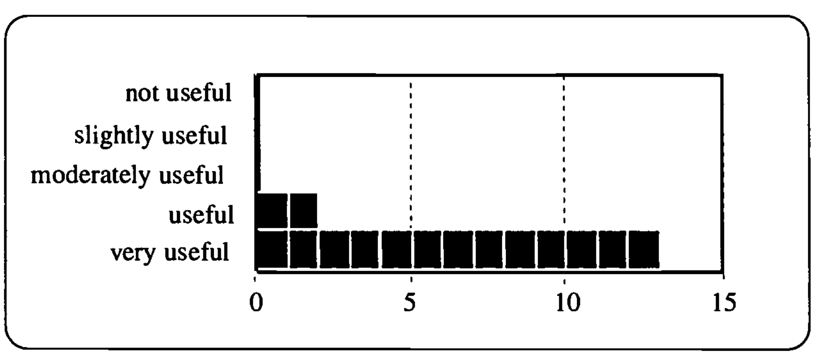

Figure 8. Numbers of students (in the PAL group) giving the indicated responses to the question: " How useful were these computer tutorials in helping you learn to apply Newton's laws?"

Reporting about her interview with the students in the Tutoring group, she writes:

> "The two students ... absolutely raved about the impact it had on their understanding of this section of the course. Both claimed to have asked numerous questions of the 'tutors' and felt that they had a much 'deeper' and 'conceptual' understanding of the principles underlying the problem than they had of previous material in the same course."

By contrast, reporting about her interview with the students in the PAL group, she writes:

> "The two students who worked on the computer tutorials also raved about their experience, although the way they phrased the 'outcomes' of the experience was a bit different from those students above. One of the students said he now is 'in the habit of doing certain things/asking certain questions' during the problem solving process, and the other said that what has stuck in her head was the process you should go through to solve a problem. They both reiterated (in case I didn't get it, I think) that they learned not only the content, but also the process of solving physics problems. ... Like the students above, these two students claimed to understand this material much better than previous material, and they attribute this to the computer tutorial."

These students (unlike those in the Tutoring Group) seem thus to have acquired from the PAL tutorials a more explicit knowledge about relevant thinking processes. (It is noteworthy that the students acquired this knowledge merely by working with the computer programs, but were otherwise never told that these were designed to teach thinking skills.)

Finally, the interviewer reports these concluding student comments:

> "The four students involved in the small group tutoring and the computer tutorial all strongly recommend continuation of these learning mechanisms. All agreed that they would take advantage of them if they were available for the physics course and other courses as well."

6. Discussion and implications

The preceding pages described the use of a computer-implemented reciprocal-teaching strategy to help students learn some important cognitive abilities. Our work has, up to now, been merely exploratory. Thus the computer tutorials constructed by us have just been prototypes and data about their effectiveness have only been obtained from a pilot experiment. Hence there remain many opportunities for further investigations and extensions of our proposed instructional approach.

Basic investigations. It would be useful to investigate in greater detail how the proposed reciprocal-teaching strategy promotes effective learning and how it might be improved. This could be done by making detailed observations of individual students working with PAL tutorials. Furthermore, these tutorials are programmed so as to keep a record of all the actions performed by a student on the computer. The analysis of these records provides then also detailed information about the learning processes of students working with the tutorials.

Teaching other thinking abilities. The present PAL tutorials were designed to teach students the ability to interpret and apply one particular principle, Newton's law of mechanics. It would clearly be possible to use the same approach to teach also other important principles (e.g., the energy law, the momentum law, or other principles outside the domain of mechanics).

However, the computer-implemented reciprocal-teaching strategy could also be used to teach abilities other than the interpretation of *principles*. (a) For example, it could be even more readily used to teach the interpretation of important *concepts* that are often difficult for many students (e.g., concepts like acceleration, work, potential energy, and others). (b) Furthermore, it would be useful to teach important *problem-solving abilities* (e.g., the abilities to analyze problems and to make the judicious decisions needed to construct their solutions).

Extensions to other domains. The same kinds of conceptual and problem-solving abilities could, of course, also be usefully taught in domains outside of our present prototype domain of mechanics. For example, similar approaches could be used for teaching electricity and magnetism, for teachng calculus, or for teaching in domains outside the natural sciences.

Teaching general cognitive abilities. Our reciprocal-teaching strategy deals very explicitly with decision making, implementing, and assessing. The consistent and repeated use of this strategy to teach a variety of specific concepts and principles could then also help students to acquire improved *general* abilities of deciding, implementing, and assessing — abilities that they themselves could then transfer to other learning tasks. The teaching of such general learning abilities is clearly an ambitious aim, but some of our past work suggests that it might be possible to achieve[14].

Practical applications in courses. Computer tutorials of the kind described in the preceding pages could be very useful in actual courses.

(a) They could be used in recitation sections where students might work with the computers singly or in pairs. The students, always actively engaged, would then receive good individual guidance and feedback while a teaching assistant could answer any questions not satisfactorily handled by the computers.

(b) They could be used for homeworks that students could do on their own, yet with good guidance and feedback. (Access to e-mail would still allow students to get needed additional assistance from an instructor.)

(c) They would also be useful to help students periodically review what they have learned and thus to consolidate their knowledge.

For example, it is fairly clear how we might build on our prototypes to construct further computer tutorials that could be very useful in an introductory college physics course. Indeed, such tutorials could have great practical utility even if they were no better than those used in our pilot experiment (i.e., even if they could merely prevent half the class from falling below test scores of 65%).

Constructing PAL tutorials for an entire such course would be quite feasible and not excessively expensive (especially since the initial cost could later be amortized by repeated and widespread use of the tutorials). However, it is doubtful whether we shall have even the minimal resources necessary to produce such practically useful computer tutorials.

7. Acknowledgments

The work described in this paper was partially supported by National Science Foundation grant # MDR-9150008. Eric S. Zeisloft helped with much of the computer programming. We are indebted to Jill H. Larkin for many useful comments, and particularly for encouraging us to undertake the pilot experiment and helping with its implementation. We are grateful to Susan Ambrose for interviewing some of the students in our pilot experiment. Finally, we wish to thank Professor Gregg Franklin for his cooperation in letting us run our pilot experiment with students from his physics class.

Footnotes and References

* Also with the Departments of Physics and Psychology at Carnegie Mellon University.

† Student in the graduate program of the School of Education at the University of Pittsburgh.

1. McDermott, L. C. (July 1984) Research on conceptual understanding in mechanics, Physics Today, 37, 24-32.

2. Halloun, I. A. & Hestenes, D. (1985). The initial knowledge state of college students, American Journal of Physics, 53, 1043-1055.

3. McDermott, L. C. & Shaffer, P. S. (1992). Research as a guide for curriculum development: An example from introductory electricity. Part I: Investigation of student understanding. American Journal of Physics, 60, 994-1003.

4. Reif, F. & Allen, S. (1992). Cognition for interpreting scientific concepts: A study of acceleration. Cognition and Instruction, 9, 1-44.

5. Reif, F. (1995). Millikan Lecture 1994: Understanding and teaching important scientific thought processes. American Journal of Physics, 63, 17-32.

6. Reif, F. (1987). Interpretation of scientific or mathematical concepts: Cognitive issues and instructional implications. Cognitive Science, 11, 395-416.

7. Heller, J. I. & Reif, F. (1984). Prescribing effective human problem-solving processes: Problem description in physics. Cognition and Instruction, 1, 177-216.

8. Eylon, B. & Reif, F. (1984). Effects of knowledge organization on task performance. Cognition and Instruction, 1, 5-44.

9. Labudde, P., Reif, F., & Quinn, L. (1988). Facilitation of scientific concept learning by interpretation procedures and diagnosis. International Journal of Science Education, 10, 81-98.

10. Reif, F. (1995) Understanding basic mechanics (Text and Workbook). New York, NY: John Wiley & Sons.

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

12. Brown, A. L. & Palincsar, A. S. (1989). Guided cooperative learning and individual knowledge acquisition. In In L. B. Resnick (Ed.), Knowing, learning, and instruction: Essays in honor of Robert Glaser (pp. 393-451). Hillsdale, NJ: Lawrence Erlbaum.

13. The object must be a "particle", i.e., an object whose motion can be adequately described by that of a single point. (For example, this is the case if the object is sufficiently small.)

14. Reif, F., Larkin, J. H., & Brackett, G. C. (1976). Teaching general learning and problem-solving skills. American Journal of Physics, 44, 212-217.

TM026556

AREA 1997

U.S. DEPARTMENT OF EDUCATION

Office of Educational Research and Improvement (OERI)

Educational Resources Information Center (ERIC)

ERIC®

REPRODUCTION RELEASE

(Specific Document)

I. DOCUMENT IDENTIFICATION:

Title: Students and computers coaching each other: A method for Teaching Important Thinking skills

Author(s): Frederick Reif & Lisa A. Scott

Corporate Source:	Publication Date:

II. REPRODUCTION RELEASE:

In order to disseminate as widely as possible timely and significant materials of interest to the educational community, documents announced in the monthly abstract journal of the ERIC system, *Resources in Education* (RIE), are usually made available to users in microfiche, reproduced paper copy, and electronic/optical media, and sold through the ERIC Document Reproduction Service (EDRS) or other ERIC vendors. Credit is given to the source of each document, and, if reproduction release is granted, one of the following notices is affixed to the document.

If permission is granted to reproduce the identified document, please CHECK ONE of the following options and sign the release below.

[✓] **Check here**

Permitting microfiche (4"x 6" film), paper copy, electronic, and optical media reproduction

Sample sticker to be affixed to document

"PERMISSION TO REPRODUCE THIS MATERIAL HAS BEEN GRANTED BY

Sample

TO THE EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)."

Level 1

Sample sticker to be affixed to document

"PERMISSION TO REPRODUCE THIS MATERIAL IN OTHER THAN PAPER COPY HAS BEEN GRANTED BY

Sample

TO THE EDUCATIONAL RESOURCES INFORMATION CENTER (ERIC)."

Level 2

[ ] **or here**

Permitting reproduction in other than paper copy.

Sign Here, Please

Documents will be processed as indicated provided reproduction quality permits. If permission to reproduce is granted, but neither box is checked, documents will be processed at Level 1.

"I hereby grant to the Educational Resources Information Center (ERIC) nonexclusive permission to reproduce this document as indicated above. Reproduction from the ERIC microfiche or electronic/optical media by persons other than ERIC employees and its system contractors requires permission from the copyright holder. Exception is made for non-profit reproduction by libraries and other service agencies to satisfy information needs of educators in response to discrete inquiries."

Signature: Frederick Reif	Position: Professor
Printed Name: Frederick Reif	Organization: Carnegie Mellon University
Address: CIL, Hamburg Hall, CMU, Pittsburgh, PA 15213	Telephone Number: (412) 268-5713
	Date: 19 March 1997

OVER

CUA

THE CATHOLIC UNIVERSITY OF AMERICA
Department of Education, O'Boyle Hall
Washington, DC 20064
202 319-5120

February 21, 1997

Dear AERA Presenter,

Congratulations on being a presenter at AERA[1]. The ERIC Clearinghouse on Assessment and Evaluation invites you to contribute to the ERIC database by providing us with a printed copy of your presentation.

Abstracts of papers accepted by ERIC appear in *Resources in Education (RIE)* and are announced to over 5,000 organizations. The inclusion of your work makes it readily available to other researchers, provides a permanent archive, and enhances the quality of *RIE*. Abstracts of your contribution will be accessible through the printed and electronic versions of *RIE*. The paper will be available through the microfiche collections that are housed at libraries around the world and through the ERIC Document Reproduction Service.

We are gathering all the papers from the AERA Conference. We will route your paper to the appropriate clearinghouse. You will be notified if your paper meets ERIC's criteria for inclusion in *RIE*: contribution to education, timeliness, relevance, methodology, effectiveness of presentation, and reproduction quality. You can track our processing of your paper at http://ericae2.educ.cua.edu.

Please sign the Reproduction Release Form on the back of this letter and include it with **two** copies of your paper. The Release Form gives ERIC permission to make and distribute copies of your paper. It does not preclude you from publishing your work. You can drop off the copies of your paper and Reproduction Release Form at the **ERIC booth (523)** or mail to our attention at the address below. Please feel free to copy the form for future or additional submissions.

Mail to:

AERA 1997/ERIC Acquisitions
The Catholic University of America
O'Boyle Hall, Room 210
Washington, DC 20064

This year ERIC/AE is making a **Searchable Conference Program** available on the AERA web page (http://aera.net). Check it out!

Sincerely,

Lawrence M. Rudner, Ph.D.
Director, ERIC/AE

---

[1]If you are an AERA chair or discussant, please save this form for future use.