COMPUTER PROBLEM-SOLVING COACHES

It is well documented that a targeted curriculum based on the cognitive apprenticeship approach can help students become better problem solvers in introductory physics courses. However, the efficiency of these curricula is constrained by the restricted amount of time available for students to practice solving problems while receiving coaching, either from instructors or peers. Well-designed web-based computer programs might provide a way around this limitation by providing students with effective coaching outside of the classroom. We describe an on-going effort to develop and assess such computer coaches.

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Introduction and Background

Researchers have shown in both small-scale experiments and in classroom settings that it is possible, through targeted efforts, to improve students' problem-solving skills significantly (e.g., Bolton & Ross, 1997; J. Heller & Reif, 1984; P. Heller, Keith, & Anderson, 1992; Larkin & Reif, 1979; Mettes, Pilot, & Roossink, 1981; Van Heuvelen, 1991; Wright & Williams, 1986). A common thread running through these efforts is that they all are either explicitly or implicitly based on the cognitive apprenticeship model (Collins, Brown, & Newman, 1989).

In a cognitive apprenticeship approach to teaching problem solving, the instructor first models good problem-solving technique, explicating the cognitive processes involved by making explicit reference to a general and systematic framework for solving problems. The framework is based on the heuristics and strategies that expert problem solvers use to attack problems. The Minnesota problem-solving framework, shown in Figure 1, is a typical example. It makes explicit the steps experts take to plan, execute, and evaluate a solution (K. Heller & P. Heller, 1997; Leonard, Dufresne, & Mestre, 1996). Although the framework is presented as a list, solving a problem is not a linear or algorithmic process. Instead, the process is actually quite complex; one might need to loop back and repeat a previous step within the framework. The framework shown is merely a method for organizing the process and is not a recipe for solving problems.

Next, students practice using the framework to solve problems with coaching from an instructor or peers as needed (P. Heller, Keith, & Anderson, 1992; Johnson, 2001). Finally, students attempt to solve problems on their own. This web of modeling, coached practice, and individual practice continues as students gain proficiency and as they do, the instructional scaffolding is gradually withdrawn or faded. In contrast, traditional forms of instruction are much less explicit about the problem-solving process. They often present students with models of finished solutions that give no indication of the decision-making process that went into their creation and have little or no individual coaching component.

Minnesota problem solving framework

1. Focus the problem
   - Draw a picture incl. given information
   - Determine question to be answered
   - Determine approach to use

2. Describe the physics
   - Draw diagrams and define physical quantities
   - Determine target quantities
   - Write down quantitative relationships

3. Plan the solution
   - Select an equation containing the target quantity
   - Identify other unknowns in equation
   - Solve a sub-problem to find each unknown
   - Check units of result

4. Execute the plan
   - Calculate value of target quantity

5. Evaluate the answer
   - Check if answer is properly stated
   - Check if answer is unreasonable
   - Check if answer is complete

Figure 1: The Minnesota problem solving framework.

One common difficulty with all of the classroom-based efforts is that even in optimally structured courses, the amount of time available for individual coaching is limited at best. Unless students actively seek help outside regular class times, only a very few hours per week are available for students to practice solving problems while receiving feedback. Under such conditions students, especially when working independently, often revert to weak novice procedures and attempt to solve problems by haphazardly trying various equations (Larkin, McDermott, D. Simon, & H. Simon, 1980).

One approach that could give students more feedback involves the use of computer coaches. Such systems can be accessed by students at any time and thus could overcome the problem of insufficient practice time during formal class hours. Computer-based coaching is very different from on-line homework systems such as CAPA (http://www.lon-capa.org/) and WebAssign (http://www.webassign.net/), which provide students with feedback about the correctness of a final answer, but little in the way of guidance and feedback about their solution process. More sophisticated homework systems such as Tycho (http://research.physics.illinois.edu/PER/Tycho.html) and Mastering Physics (http://www.masteringphysics.com) do provide students with problem-specific hints but do not, in general, address the decision making inherent in more general problem solving. A few of the problems offered by these systems do model an organized problem-solving strategy, but these tutorial problems are, at present, not well-coordinated with the other problems that are available and cannot be customized to fit the problem-solving process modeled by a particular instructor and supported by a specific physics course.

An ambitious computer tutorial system for problem solving has been constructed at the University of Pittsburgh (http://www.andestutor.org/). The ANDES tutor (VanLehn et al., 2005) is a true intelligent tutor program in the sense that it incorporates an artificial intelligence system that attempts to determine the user's mental state and proficiency at problem solving and offers appropriate guidance and feedback. While such a system can offer many learning benefits to students who use it, it is an enormously complex program that is difficult to develop and modify. Instructors cannot adapt it to fit their course, their students, or their preferences. Furthermore, the ANDES tutor is designed to be minimally invasive and thus does not force students to practice making good decisions using an expert-like problem-solving framework. Nevertheless in the future, with the advent of more powerful computers and software architecture, the use of artificial intelligence to construct a true computer coach may prove extremely effective.

A more modest approach to creating a computer tutor to help students solve physics problems was developed at Carnegie Mellon University. These computer tutorials, called Personal Assistants for Learning (PALs), were designed to coach students through the process of applying a particular physics principle (Newton's Second Law) to solve physics problems (Reif & Scott, 1999). Those tutorials employed a cognitive analysis of the thought processes required to instantiate a particular physics principle and were based on the cognitive apprenticeship approach. However, the PALs that were constructed are limited in scope in that they were designed only to help students learn to apply a small number of physics principles or concepts.

More recently, there has been an effort to design a physics problem solving coach using the LabVIEW™ programming environment, but this is still in the beginning stages of development (Undreiu, Schuster, & Undreiu, 2008).

Developing the Computer Coaches

At the University of Minnesota, we are attempting to help introductory physics students become better problem solvers by creating computer coaching programs that strike a practical balance between complexity and customizability, while emphasizing the decision making process that is critical to problem solving. Our coaches are based on the PALs developed at Carnegie Mellon University (Reif & Scott, 1999), but are more sophisticated and generally applicable in that they are designed to help students solve problems involving any of the various principles students learn in an introductory physics course, rather than one particular principle. The design of the coaches is based on both the cognitive apprenticeship approach and research in constructing tutors for teaching cognitive skills (Anderson, Corbett, Koedinger, & Pelletier, 1995).

Like the classroom-based approaches, these computer programs coach students through the use of an expert-like framework to solve problems. The framework is based on both the process that experts use, as gleaned from expert-novice studies of problem solving (P. Heller, Keith, & Anderson, 1992), as well as a cognitive task analysis of the problem-solving process, and is made explicit to the students.

As mentioned previously, one of the drawbacks with many other computer-assisted problem-solving systems is that in an attempt to be minimally invasive, those systems do not emphasize enough the role of good decision-making in the context of an expert-like problem-solving framework. Although it is important for students to develop a problem-solving method that is comfortable and feels natural to them, it is at least as important that their fundamental approach to problem solving be a competent one. This is analogous to a coach helping a golfer to correct his swing. Even though the player's current motion might initially be more comfortable and effective, the coach corrects the swing because he or she knows that it will ultimately result in a better game. Thus, our computer coaches, in the early stages, guide students to use an expert-like framework.

Mere knowledge of a framework does not guarantee that a student will be able to use it to solve a problem, however. Successful use of the framework depends not only on a student's content knowledge, but also on the cognitive functions of deciding, implementing, and assessing (Reif & Scott, 1999). At each point in the solution process, students must decide which step in the framework to execute, whether it is the subsequent step in the framework or a previous step to which one must loop back. The student must then be able to implement that step and assess whether or not the implementation was correct. In general, novice problem solvers focus on implementing without making deliberate decisions as to what to do and without assessing the results of their implementations. A failure to make deliberate decisions often results in a student becoming "stuck" and failing to use knowledge that they possess. The lack of continuous assessment of their work not only causes students' mistakes to escape their attention, but also results in a failure to learn from those mistakes. The coaches we are developing use a modified form of the reciprocal teaching instructional method (Palincsar & Brown, 1984) to help students learn to make good decisions.

Reciprocal teaching is a method based on the cognitive apprenticeship model that was originally devised to help middle school students learn to read with good comprehension. Students and teachers take turns assuming the role of the teacher, thinking up questions to ask the other to check for comprehension of a read passage. In our modified form, there are two modes of interaction between the student and the computer coach.

In the first or "implementation" mode, the computer models for the student the process of using the framework to decide on an action. The student then implements that action and the computer models the process of assessing the student's implementation, helps the student diagnose any errors, and guides the student to make corrections before deciding on the next step to be performed. Figure 2 shows a screenshot from an implementation mode coach. In the figure, the display shows a partially completed picture ①. The computer has decided on a step ② and asks the student to find the forces acting on the train ③ . The student's implementation of this step is incorrect, selecting a force that does not exist ④. The computer provides feedback ⑤. A number to the left of each step ⑥ indicates the number of incorrect responses the student has made during the implementation of that step, while a checkmark indicates that the step was implemented correctly the first time.

In the second mode or "coaching" mode, the roles are reversed. The student acts as the coach, deciding on the action to be implemented by the computer. The computer

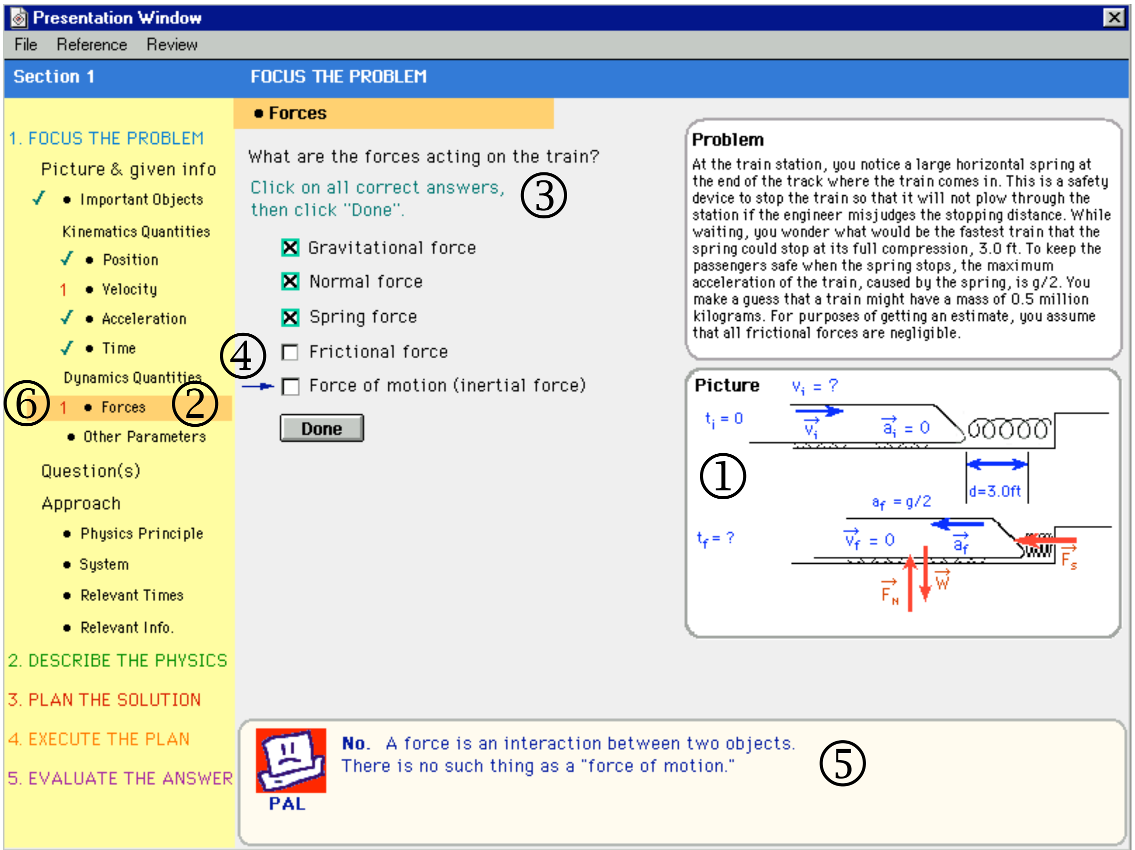

Figure 2: Screenshot from an implementation mode coach.

implements the action and the student must then assess the computer's implementation, making any necessary corrections. Figure 3 shows a screenshot from the coaching mode. The display shows a partially completed picture ①. The student has decided on a step for the computer to carry out ② but it is not appropriate at this point. The computer gives the student feedback ③.

These two modes of interaction mirror the strategy of reciprocal teaching. The student is engaged the entire time and practices the cognitive skills of decision making, implementing, and assessing, in addition to watching the computer model those skills.

Because the student must ultimately be able to solve problems independently on paper, we have also developed a third mode of interaction called the "performance" mode, which is based on the instructional strategy of learning from well-studied examples (Zhu & H. Simon, 1987). This mode reflects the fading aspect of a cognitive apprenticeship in which the scaffolding is gradually removed. In the performance mode, the computer presents a problem to the student and asks the student to solve the problem on paper, without any help, and then to enter his or her answer. If the answer is incorrect, the computer helps the student by asking questions tied to the proper application of the problem-solving framework and can give help, again in the context of the use of the framework. Figure 4 shows a screenshot from a performance mode coach.

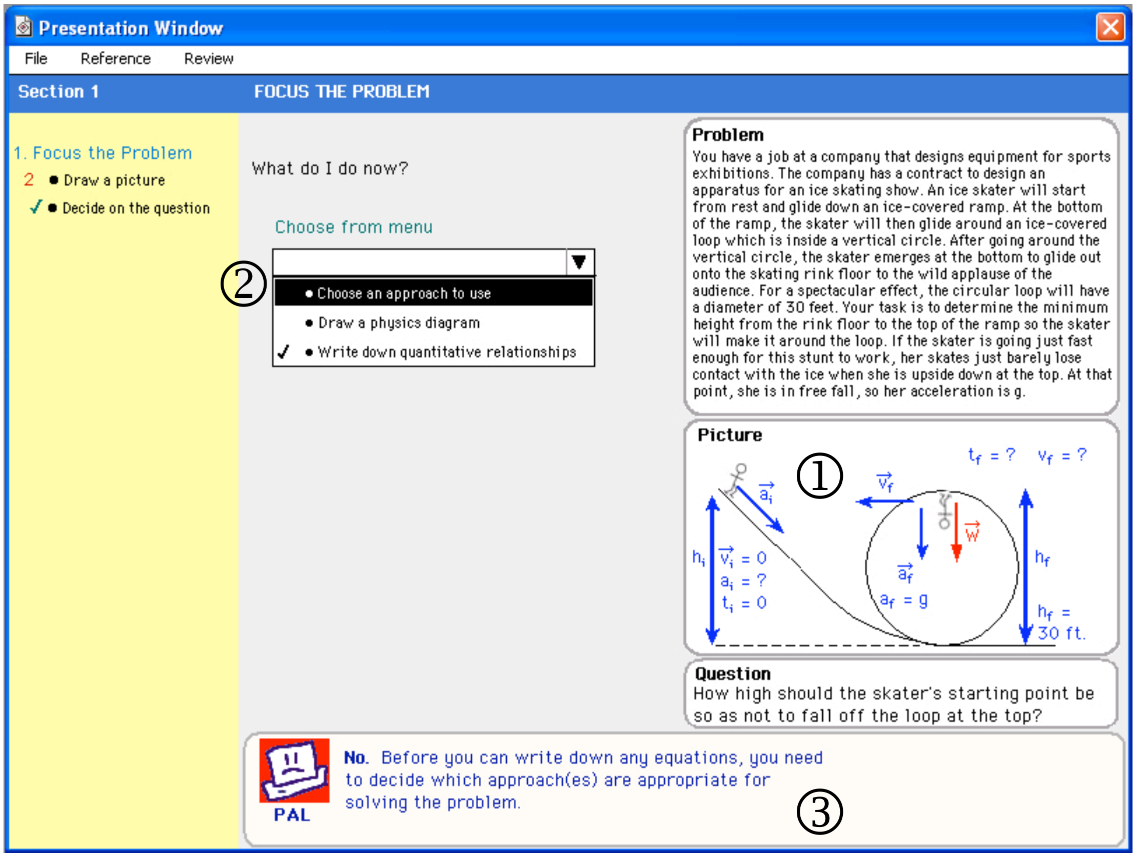

Figure 3: Screenshot from the coaching mode.

Because many typical end-of-chapter textbook problems can be solved successfully by students using novice "plug-and-chug" methods, such problems are inappropriate for motivating students to practice using an expert-like problem-solving framework. The problems built into our computer coaches are primarily “context-rich” problems (P. Heller & Hollabaugh, 1992). Context-rich problems are a scaffolding specifically designed to aid the learning of problem-solving skills. Such problems: (1) are challenging enough that students need to use a more expert-like problem-solving framework to reach a solution, (2) require students make good decisions on how to proceed with the solution, (3) have a context and motivation that appear as if they might be realistic to students, (4) require students to visualize the situation, and (5) are mathematically straight-forward to solve from basic principles in several steps.

The computer coaches are programmed in Flash, since this is a common framework that is widely accessible to all web browsers. Although most physics instructors cannot be expected to take the time to learn how to program in Flash, we are also developing tools to make it reasonably easy for even those without programming experience to create and modify their own problems and to customize the coaches for their own use.

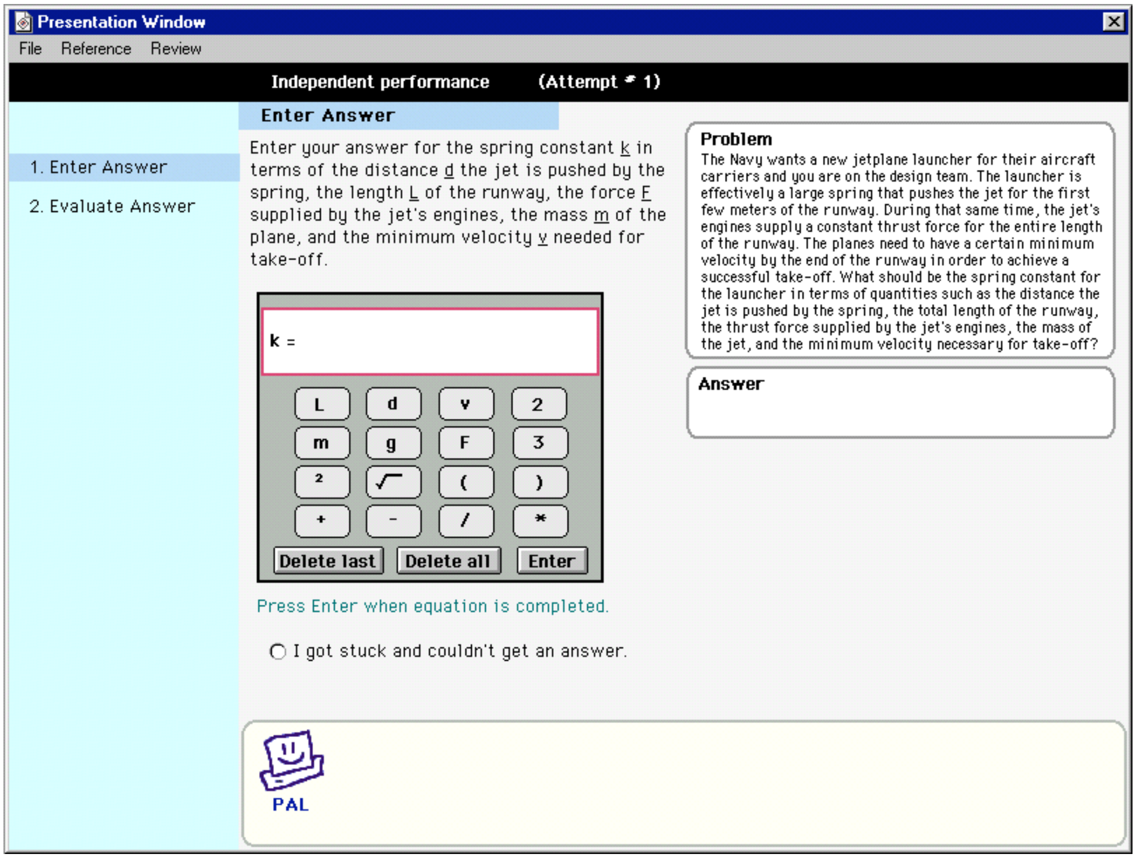

Figure 4: Screenshot from a performance mode coach.

Pilot Study

While developing the initial prototypes, we recruited small numbers of volunteer students to work through the coaches and give us feedback on their usability. Recently, on completing coaches for eight problems on the conservation of energy principle, we conducted a pilot study with students from four sections of the first semester calculus-based introductory physics courses for physical science majors and engineers at the University of Minnesota.

Volunteers were recruited to use the computer coaches with the understanding that only a limited number of them could be accommodated. From the volunteers, two groups of forty-five students were formed, matched on the basis of gender and scores on two previous exams in the class. During the two weeks preceding the exam on the conservation of energy, one group of students used the coaches to solve the eight problems while the second group received only the help normally available to students in the class, including TA and instructor office hours and campus tutoring center services. The purpose of the second group was to serve as a control group of students who were roughly equally motivated as those in the first group, but who did not use the coaches. After the exam, all 90 students' written problem solutions were collected for analysis. In addition, the 45 students who used the coaches were interviewed for their perceptions of the coaches' usability and usefulness.

Results

Because the intervention performed was minimal (coaching while solving 8 physics problems), came in the middle of a semester, and the problem-solving framework emphasized by the tutorials was not necessarily consistent with the professors' instruction, we did not expect to see large, if any differences in the problem solutions of students in the two groups. Furthermore, only one of the four instructors included context-rich problems on his exam. Indeed, no significant differences were seen between the written problem solutions of students in the two groups in terms of the use of representations, logical approach, evaluation, or correctness in solving the problems. However, this pilot study was carried out mainly to test the methodology and gather more widespread feedback on the usability of the coaches.

Students who used the computer programs were interviewed about their experience. Virtually all of the students stated that (1) they found the programs helpful to their learning, (2) the problem-solving framework coached by the programs was useful and something that they would try to use in the future, and (3) they wished that there were more such programs available. On the whole, the students found the programs easy and intuitive to work through without any outside instructions. A significant number of the students commented that they found the coaching mode programs less useful than the implementation mode or performance mode because they did not feel like they were getting practice solving a problem. We will use this and other student feedback to continue to develop and improve the coaches.

At present, we are working on expanding the number of problems and the topics they cover so that the coaches can be used throughout the entire first semester of introductory physics. To assess whether such a use of the computer coaches improves students' problem-solving skills, we plan to use a rubric we are developing in parallel that can be applied to students' written problem solutions. The design and validation of this rubric is described in the next paper in this symposium.

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