A new approach: Computer-assisted problem-solving systems

Tolga GOK

Torbali Vocational School of Higher Education
University of Dokuz Eylul, Izmir-TURKEY
E-mail: tolga.gok@deu.edu.tr

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Abstract

Computer-assisted problem solving systems are rapidly growing in educational use and with the advent of the Internet. These systems allow students to do their homework and solve problems online with the help of programs like Blackboard, WebAssign and LON-CAPA program etc. There are benefits and drawbacks of these systems. In this study, the drawbacks of this software were examined. Unfortunately, this software is insufficient to completely improve students' fundamental and conceptual understanding and problem solving completely. In this paper, problem solving is viewed as a fundamental part of learning physics, and due to the drawbacks of other software, IPSS (Integrated Problem Solving Strategy

Steps) was developed for problem solving on the computer. Using the IPSS method, the number of attempts for correct answer was eliminated to focus the students' attention on getting the correct answer with the full solution. Students' opinions toward IPSS were taken. According to their declarations, it seems that students found the program helpful for their learning on a conceptual basis.

Introduction

Computer-assisted problem solving systems are rapidly growing in educational useage. At least a hundred thousand U.S. students currently submit their homework or problem solving for computerized grading over the Web while attending real classes, and the practice is also growing rapidly in math, chemistry and other sciences (Bonham et al., 2003).

There are many Web-based educational tools available today that can be used in various ways. Some merely assist in the management of traditional lecture courses, supplement the presentation of some of the material (for example, Authorware-based visualization), provide question management and test construction (for example, Question Mark Designer), or enable instructor-student conferencing on-line (for example Alta Vista Forum). Other tools (Blackboard, WebCT, WeBWork, WebAssign, etc.) enable entire Web-based courses for either local or distance learning. For example WebCT includes management and administration, material presentation, study guides, quiz and examination modules, online help, bulletin boards, chat rooms and e-mail (Kashy et al., 1998; Hunter, 2000). Recently, LON-CAPA (The Learning Online Network with a Computer-Assisted Personalized Approach) software was developed to use in studio classes (Kashy et al., 1993). LON-CAPA is the combination of a course management system, an individualized assessment system, and a learning resources management system. LON-CAPA, a free open source software, was originally developed at Michigan State University, and has its roots in the earlier software systems including LON-CAPA (Kashy et al., 1995), Multimedia Physics (Bauer et al., 1992), and LectureOnline (Kortemeyer & Bauer, 1999). LON-CAPA has been used in many classes of physics, chemistry, calculus, biology, mathematics, psychology, statistics and several other subjects (Kashy et al., 1995; Kortemeyer et al., 2008).

LON-CAPA enables entire web-based courses for either local or distance learning. The system provides a large variety of conceptual and quantitative problem functionality for personalized assignments, quizzes and examinations (Kashy et al., 1993; Kortemeyer et al., 2008; Morrissey et al., 1995). The sophisticated LON-CAPA includes three parts; Quizzer, to create questions and prepare personalized problem sets or examinations; Grader, to record student responses and scores; and Manager, to create class reports and compile various statistical information that is available with a detailed description of the LON-CAPA (Hunter, 2000).

LON-CAPA, while similar to many others (WebCT, WebAssign, etc.) in most aspects, differs in three important ways. The first is its capability to randomize problems, both algorithmic numerical exercises as well as problems that are qualitative and conceptual, so numbers, options, images, graphs, formulas, labels, etc., differ from student to student (Kashy et al., 1995). The students can thus discuss the assignments, but cannot simply exchange answers.

The second is in the tools provided that allow instructors to collaborate in the creation and sharing of content in a fast and efficient manner, both within and across institutions, thus performing the first goals of the WWW. Most course management systems are built around the course as the main entity, and learning content is then uploaded to the courses. At the end of the semester, most systems allow export of the content to an instructor's personal computer, and then need re-uploading in another semester. Within LON-CAPA, content is stored independently of a specific course in a shared cross-instructional content pool.

The third is its one-source multiple target capabilities, meaning its ability to automatically transform one educational resource, for example a numerical or conceptual homework question, into a format suitable for multiple uses. The same code, which is used to present problems for on-line homework, can also create an online examination or a print bubble sheet examination which is later machine scored (Kortemeyer et al., 2005).A detailed description of the LON-CAPA system is available elsewhere (Kashy et al., 1993; Kashy et al., 1995; Kashy et al., 1998; Kortemeyer et al., 2008; Thoennessen & Harrison, 1996).

Advantages of computer-assisted problem solving systems give immediate feedback to students and allow automatic grading for instructors. Automatic grading can be helpful to teachers by saving time grading students' assignments and/or exams. Also, it can encourage students to take problem solving more seriously because they know it will be graded, and the grade will be recorded.

Students can get immediate feedback on their answers to problems and sometimes even hints or intelligent help towards solving problems (Mendicino et al., 2009).

Although there are benefits to using these computer-assisted problem-solving systems, there can be drawbacks, as well. Many of these systems require students to enter a single answer for each problem, and they do not consider or take note of a students' solution. Students may also try to do more math in their heads and do less scrap work, which can help them to be more organized. Teachers may spend less time looking at their students' solutions and figuring out exactly where they are having difficulties. Finally, these systems often do not consider student work; cheating may be easier among students because they could possibly get the answers from their friends without having to show how they arrived at them (Bonham et al., 2003; Titus et al., 1998). These issues are not new, but they are more important now that the Internet has eliminated many of the technical barriers to using automatic computer-assisted problem solving systems.

As mentioned above, 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 component one (Hsu & Heller, 2009).

Computer-assisted problem solving systems were examined in this research. LON-CAPA was chosen among the others. This program has been used since 2007 at the Colorado School of Mines (CSM). Also the advantages and drawbacks of this program were published in literature (Bauer & Kortemeyer, 2005; Kashy et al., 2001-2003; Kortemeyer & Bauer, 1999; Kortemeyer et al., 2008; Kortemeyer, 2009). One of the major drawbacks of LON-CAPA is that the problems in LON-CAPA include a lack of detailed solution steps, and the danger of multiple tries for gaining results encourages students' lazy habits. Also, corrective hints shift the focus away from the goal of concept understanding to task completion (Kohl et al., 2008). In that case, students don't spend time to understand the concept behind the problem and continue to adopt formulaic approaches to problem solving. They tend to solve plug-and-chug (single formula problems) or "just like the example" problems rather than complex problems with well-presented solution steps. This does not mean that equations are not important or useful. It means that equations are needed only at the end of the problem solving process, when principles, laws and definitions are applied. Generally, when students come across a challenging problem, they give up or get stuck on finding a solution. Current LON-CAPA problems do not encourage students to think critically and to solve the problem in a well-defined way. The question is how to get students actively intellectually involved in thinking about the fundamental concepts? We know that fundamental ideas are not easily absorbed by students. But we can adapt their minds to think in an organized way while they are solving a complex problem. This can be possible by teaching the various problem solving strategies to students, which are explained in the next section.

Problem Solving

Most researchers working on problem solving (Dewey, 1910; Newell & Simon, 1972 etc.) agree that a problem occurs only when someone is confronted with a difficulty for which an immediate answer is not available. However, difficulty is not an intrinsic characteristic of a problem because it depends on the solver's knowledge and experience (Garrett, 1986; Gil-Perez et al., 1990). So, a problem might be a genuine problem for one individual, but might not be for another. In short, problem solving refers to the effort needed in achieving a goal or finding a solution when no automatic solution is available.

One of the fundamental achievements of education is to enable students to use their knowledge in problem solving (Reif et al., 1976; McDermott, 1991; Heller et al., 1992). Therefore, many researchers find that their students do not solve problems at the necessary level of proficiency (Van Heuvelen, 1991; Reif, 1995; Redish et al., 2006). To help improve the teaching and learning of physics problem solving, studies began in the 1970's (McDermott & Redish, 1999).

Research on developing an effective general instruction for physics problem solving started at least 50 years ago (Garrett, 1986) and changed after the late 1970s with the works of Larkin & Reif (1979), Larkin et al. (1980), Chi et al. (1981), Larkin (1981), Heller & Reif (1984), Reif, (1995), Dufrense et al. (1997), Kozma & Russell (1997), Mestre (2001), Kozma (2003) and Kohl et al. (2007). Most of the research during this period aimed to identify the differences between experienced and inexperienced physics problem-solvers.

These studies show that the experienced problem solvers were individuals with important knowledge, experience and training in physics, and so the process of reaching a solution was both easy and automatic for them. In contrast, the inexperienced problem solvers had less knowledge, experience and training in physics, which means that they were facing real problems.

In physics problems, inexperienced problem solvers tend to spend little time representing the problem and quickly jump into quantitative expressions (Larkin, 1979). Instructors have found that inexperienced problem solvers carry out problem solving techniques that include haphazard formula-seeking and solution pattern matching (Mazur, 1997; Van Heuvelen, 1991). By contrast, experienced problem solvers solve problems by interjecting an another step of a qualitative analysis or a low-detail review of the problem before writing down equations (Larkin, 1979) This qualitative analysis used by experienced problem solvers, such as a verbal description or a picture, serves as a decision guide for planning and evaluating the solution (Larkin & Reif, 1979; Kohl & Finkelstein, 2008). Although this step takes extra time to complete, it facilitates the efficient completion of further solution steps and usually the experienced problem solver is able to successfully complete the problem in less time than an inexperienced problem solver.

Reif & Heller (1982) discussed this view of problem solvers by comparing and contrasting the problem solving abilities of inexperienced and experienced problem solvers. Their findings showed that the principal difference between the two was in how they organize and use their knowledge about solving a problem. Experienced problem solvers rapidly re-describe the problem and often use qualitative arguments to plan solutions before elaborating on them in greater mathematical detail. Inexperienced problem solvers rush into the solution by stringing together miscellaneous mathematical equations and quickly encounter difficulties. Inexperienced problem solvers do not necessarily have this knowledge structure, as their understanding consists of random facts and equations that have little conceptual meaning. This gap between experienced and inexperienced problem solvers has been well studied with an emphasis on classifying the differences between students and experienced problem solvers in an effort to discover how students can become more expert-like in their approach to problem solving (Larkin et al., 1980; Reif & Allen, 1992).

As well as differences in procedures, experienced and inexperienced problem solvers differ in their organization of knowledge about physics concepts. Larkin

(1979) suggested that experienced problem solvers store physics principles in memory as chunks of information that are connected and can be usefully applied together, whereas inexperienced problem solvers must inefficiently access each principle or equation individually from memory. Because of this chunking of information, the cognitive load on an experienced problem solver's short-term memory is lower, and they can devote more memory to the process of solving the problem (Sweller, 1988). For inexperienced problem solvers, accessing information in pieces places a higher cognitive load on short-term memory and can interfere with the problem solving process.

According to these findings, instead of researching the advantages of experienced problem solvers to produce a problem solving instruction, researchers can try to examine students' difficulties by confronting real physics problems and showing methods to overcome these difficulties. By researching the characteristics of students' problem solving patterns, a general instruction guideline can be produced to meet the various patterns of physics problem solving found among students. It may be that some inexperienced problem solvers have already had good physics problem solving skills that can serve as examples for other inexperienced problem solvers.

Most of the researchers examined general and specific problem solving strategies. The most notably general strategies are Polya's (1945) and Dewey's (1910) problem solving strategy steps. Dewey (1910) cited for his four steps (problem's location and definition, suggestion of possible solution, development by reasoning the bearings of the solution and further observation and experiment leadings to its acceptance or rejection) problem solving strategy.

Polya (1945) is cited for his four steps problem solving strategy. The first step is Understanding the Problem, by identifying the unknown, the data and the condition, and then drawing a figure and introducing a suitable notation. The second step is Devising a Plan, in which the solver seeks a connection between the data and the unknown. If an immediate connection is not found, the solver considers related problems or problems that have already been solved, and uses this information to devise a plan to reach the unknown. In the third step, Carrying out the Plan, the steps outlined in part two are carried out, and each step is checked for correctness. In the final step Looking Back, the problem solution is examined, and arguments are checked.

Reif et al. (1976) tried to teach students a simple problem solving strategy consisting of the following four major steps: Description, which lists clearly the given and wanted information. Draw a diagram of the situation. The next step, Planning, selects the basic relations suitable for solving the problem and outline how they are to be used. The Implementation step performs the preceding plan by doing all necessary calculations. The final step is Checking, which ensures that each of the preceding steps was valid and that the final answer makes sense.

Over the past 40 years, several physics problem solving methods have used the logical problem solving model (Heller & Heller, 1995); teaching a simple problem solving strategy (Reif et al., 1976); the systematic modelling method (Savage & Williams, 1990); the didactic approach (Bagno & Eylon, 1997); the collaboration method (Harskamp & Ding, 2006); the computer-assisted instruction (Bolton & Ross, 1997; Pol, 2005) and the translating context-rich problem (Heller et al., 1992; Heller & Hollabaugh, 1992; Yerushalmi & Magen, 2006); the creativeness approaches in problem solving (Walsh et al., 2007; Bennett, 2008); and the epistemic games (Tuminaro & Redish, 2007) have all been produced by researchers to help students improve their problem solving.

The steps of the University of Minnesota problem solving strategy include Focus the Problem, which involves determining the question and sketching a picture, and selecting a qualitative approach. The next step, Describe the Physics, includes drawing a diagram, defining symbols, and stating quantitative relationships. The Plan a Solution step entails choosing a relationship that includes the target quantity, undergoing a cycle of choosing another relationship to eliminate unknowns and substituting to solve for the target. The step Execute the Plan involves simplifying an expression, and putting in numerical values for quantities if requested. The final step is Evaluate the Answer, which means evaluating the solution for reasonableness, and to check that it is properly stated (Heller & Heller, 1995).

Loucks (2007) introduced a method for solving university physics problems, particularly when algebra is involved, which is similar to Savage and Williams' problem solving. For Loucks, the most important factor is to setup the problem, so that the solver can determine which equations are suitable. Once it is setup, the problem becomes simply a mathematical problem. Loucks recommended five steps to effectively solve physics problems with algebra; a) identify the type of problem (for example, concept, keyword or feature); b) sort by interval and/or object (e.g., list everything, draw diagram); c) find the equation and unknowns, try to relate the intervals; d) outline solution or make a chain of reaction; and e) do the mathematics.

Mayer (2008) asserted that effective practice in problem solving should be given in a structured way, but not in a step-by-step procedure. He concluded that problem-solving programs are most effective when they focus on problem solving not as a single intellectual ability, but as a collection of smaller component skills. He stressed that successful problem-solving training involves specific problem-solving skills, contextualized tasks that students are expected to perform in school, practice in the process of problem-solving, discussion of the problem-solving process, and teaching problem-solving before students have fully mastered content, knowledge of a domain. He also stressed that problem solving training should be provided in addition to developing domain-specific content knowledge. Students need to learn domain-specific problem-solving skills in order to become successful learners in physics.

Tóth & Sebestyén (2009) studied the importance of the cognitive variables to problem solving in chemistry. They assumed that the success of the problem solving is basically determined by three block variables containing six predictor variables:

1. Prior knowledge:

   a) Specific knowledge: knowledge directly related to the problem.

   b) Non-specific but relevant knowledge: knowledge related to the subject area of the problem.

2. Linkage:

   a) Concept relatedness: relatedness between concepts involved in problem solving.

   b) Idea association: linkage between the information retrieved from the existing knowledge structure and the external cues.

3. Problem recognition skill:

a) Problem translating skill: the capacity to comprehend, analyzes, interpret and define a given problem.

b) Prior problem solving experience: the prior experience in solving the similar problems.

Based on empirical research, they found that the significance of the above variables depends on the topics and level of the chemistry problems; however, these differences in topics and levels have little effect on the importance of these variables on problem-solving performance.

Kowalski et al. (2009) examined the review of problem solving strategies. Their study was a modification of well-established steps used to teach increased competency in problem-solving strategies in engineering courses. They combined the problem solving strategy steps with three steps (identifying of the fundamental principle, solving and checking).

In this research a combination of problem solving strategies and a computer based learning tool is performed (Integrated Problem Solving Strategy steps (IPSS)) to increase the benefits of the current LON-CAPA education system.

Integrated Problem Solving Strategy Steps

In this research, the author presents the selected and modified three steps in the problem solving strategy based on the problem solving strategies reported by the researchers mentioned before. The developed IPSS (Integrated Problem Solving Strategy Steps) could be summarized as follows:

I. Identifying the Fundamental Principle(s): In the first and most important step, a student should accurately identify and understand the problem. A student should examine both the qualitative and quantitative aspects of the problem and interpret the problem in light of his/her own knowledge and experience. This enables a student to decide whether information is important and what other information may be needed. In this step students must: (i) simplify the problem situation by describing it with a diagram or a sketch in terms of simple physical objects and essential physical quantities; (ii) restate what you want to find by naming specific mathematical quantities; and (iii) represent the problem with formal concepts and principles.

II. Solving: A student uses qualitative understanding of the problem to prepare a quantitative solution. Dividing the problem into subproblems is an effective strategy for constructing the solution. Thus, the solution process involves repeated applications of the following two steps: (i) choosing some useful subproblems and (ii) carrying out the solution of these subproblems. These steps can then be recursively repeated until the original problem has been solved. The decisions needed to solve a problem arisen from choosing subproblems. The two main obstacles can be: (i) lack of needed information and (ii) available numerical relationships that are potentially useful, but contain undesirable features. These choices are promoted if there are only few reasonable options among which a student needs to choose. An effective organization of knowledge has crucial importance in making easy the decisions needed for problem solving. The organization done after applying the particular principle is facilitated by all of a student's previously gained technical knowledge. The final step contains plugging in all the relative quantities into the algebraic solution to determine a numerical value for the wanted unknown quantity (ies).

III. Checking: In the final step, a student should check the solution to assess whether it is correct and satisfactory and to revise it properly if any shortages are detected by following this checklist: (i) Has all wanted information been found?; (ii) are answers expressed in terms of known quantities?; (iii) are units, signs or directions in equations consistent?; (iv) are both magnitudes and directions of vectors specified?; (v) are answers consistent with special cases or with expected functional dependence?; (vi) are answers consistent with those obtained by another solution method?; (vii) are answers and solution as clear and simple as possible?; and (viii) are answers in general algebraic form?

Those IPSS are expected to eliminate the potential drawback of the LON-CAPA problems/homework and make all students experienced problem solvers in computer-based problems. In the Appendix, a sample problem is presented with these Integrated Problem Solving Strategies steps (IPSS) as screenshots. In the first screen, students are asked to understand and choose related fundamental concept(s). The second display leads to the students' selecting the correct diagram or sketch to make the concept clear and then to restate the specific mathematical quantities. In the third window, students are expected to fill the equation blanks by selecting parameters from symbolic/mathematical expression boxes and to calculate the numerical quantities with units. The fourth screen encourages students to check the solution steps with the checklist; if the entry is correct on the previous screen, and at the bottom of the page they confirm the numerical result. On the last page the students review the instructor's solution key.

The current (LON-CAPA) and new design (IPSS) of computer-based problem solving systems was investigated with a pilot study that is detailed below. Also, the perceptions of the volunteer students who attended this pilot were observed.

Pilot Study

While developing the initial prototype of the IPSS, small numbers of volunteer students (35 students) are conducted to work through the systematic problem solving and give feedback on the strategy usability. In the interview stage, students were asked to be interviewed voluntarily about LON-CAPA and IPSS. The purpose of the interviews was to learn student's approaches to the current format (which part should be improved prior to the IPSS application) and improved format (what are their perceptions). The problems shown in the introductory calculus-based physics course on LON-CAPA were selected in the application. Problems were presented to students first on LON-CAPA, then on IPSS, and they were asked to solve the problems to compare two problem solving mediums.

In the first application (LON-CAPA), students entered the answer to the problem on the computer. If the answer is correct, they saw the "correct" message in a green box. If it's incorrect, the "incorrect" message appeared. They were allowed 99 attempts to find the correct answer. It's obvious that in this kind of problem solving system, the "correct" answer is sufficient to be evaluated.

Some students (80.3%) declared that LON-CAPA helped students to take a better set of notes in "PDF" format. Few (10.3%) were happy with its capability to randomize problems, both algorithmic numerical exercises, as well as problems that are qualitative and conceptual, including numbers, options, images, graphs, formulas, labels, etc. The students can discuss the assignments, but cannot simply exchange answers.

Most of the students (76.5%) pointed out that some technical features of LON-CAPA could be improved:

i) Detailed Feedback: in current version there is no detailed solution way showing the calculation steps to the students.

ii) Decrease the number of attempts: students felt demoralized when not getting correct the answer after 99 attempts.

iii) Incorporation of Simulations: students do not visualize the real-world concepts.

In the second application (IPSS), the same problems were given and needed to be solved. In the first stage, students were responsible with finding the fundamental principle. If it's known by student, s/he could proceed to the second stage. The second stage was about the concepts asked in the problem. The questions related with the problem were asked in the later stage. Two boxes were given to select the proper parameters included in the equation and to write the necessary equation. In the last stage, students checked the problem solving steps and submitted their solutions to the computer system. After all these steps, the solution of the instructor was shown. With the help of this answer, students could compare their solutions with the solution key.

Virtually most of the students (85.2%) stated that they found the IPSS helpful to their learning because of detailed solution steps, although some students (8.4%) thought IPSS takes too long to reach the final solution. At the same time, 92.5% of students reported that the problem solving strategy steps by the computer programs was useful and something that they would try to use in the future.

Further, 76.7% of students said that they were more attentive when IPSS was used and 81.3% felt more motivated. Finally, 79.8% of students wished that there were more similar programs available. On the whole, the students found the IPSS easy and intuitive to work through any outside instructions.

Conclusion and Discussion

It is remarked that computer-assisted problem solving systems are not sufficient to completely improve students' fundamental and conceptual understanding and problem solving skills. The most important reason is that students focus on getting the correct answer by trial-and-error strategy, rather than by solving the problem in well-defined steps. IPSS (Integrated Problem Solving Steps) were developed and incorporated with a LON-CAPA sample problem to encourage students to think in an organized way even when they solve complex problems. Using the IPSS method the number of attempts for correct answers was eliminated to focus the students' attention on getting the correct answer with the full solution. If developed, problem solving strategy steps (IPSS) can be introduced into the LON-CAPA problems, and it is expected that students will become experienced problem solvers. IPSS also can be used with other online homework software (WebAssign, WWWAssign, etc.) and adapted for all undergraduate level science and engineering courses because students need to develop critical thinking in problem solving skills. Even though it seems that this problem solving method takes up students' time, students should spend more time and effort to engage with the problem in both conceptual and problem solving aspects. The value of this program can be useful to students of varying abilities in problem solving, from the inexperienced problem solver to the experienced problem solver. This will encourage them to transfer their skills to real world applications. From these results and students' perceptions, the author concludes that students should be taught both concepts and problem solving skills clearly if we want students to be proficient at both, and IPSS seems to be a means to perform this idea.

References

Bagno, E., & Eylon, Bat-S. (1997). From problem solving to a knowledge structure: An example from the domain of electromagnetism. *American Journal of Physics, 65*(8), 726-736.

Bauer, W., Benonson, W., & Westfall, G. D. (1992). *Multimedia Physics*, CD ROM.

Bauer, W., & Kortemeyer, G. (2005). Research on learning in LON-CAPA: Multiple content representations, test data banks, in computer based learning in science. *Conference Proceeding Computer Based Learning in Science*, University of Zilina, Slovakia.

Bennett, W. (2008). Problem solving: can anybody do it? *Chemistry Education Research and Practice, 9*, 60-64.

Bolton, J., & Ross, S. (1997). Developing students' physics problem-solving skills. *Physics Education, 32*, 176-185.

Bonham, S. W., Deardorff, D. L., & Beicher, R. J. (2003). Comparison of student performance using web and paper-based homework in college-level physics. *Journal of Research in Science Teaching*, *40*(10), 1050-1071.

Chi, M. T. H., Feltovich, P. J., & Glaser, R. (1981). Categorization and representation of physics problems by experts and novices. *Cognitive Science*, *5*, 121-152.

Dewey, J. (1910). *How we think*. London: D. C. Heath & Company.

Dufrense, R. J., Gerace, W. J., & Leonard, W. J. (1997). Solving physics problems with multiple representations. *Physics Teacher*, *35*, 270.

Garrett, R. M. (1986). Problem-solving in science education. *Studies in Science Education*, *13*, 70-95.

Gil-Perez, D., Dumas-Carre, A., Caillot, M., & Martinez-Torregrosa, J. (1990). Paper and pencil problem solving in the physical sciences as a research activity. *Studies in Science Education*, *18*, 137-151.

Harskamp, E., & Ding, N. (2006). Structured collaboration versus individual learning in solving physics problems. *International J. of Science Education*, *14*(17), 1669-1688.

Heller, J. I., & Rief, F. (1984). Prescribing effective human problem-solving processes: Problem description in physics. *Cognition and Instruction*, *1*(2), 177–216.

Heller, P. M., Keith, R., & Anderson, S. (1992). Teaching problem-solving through cooperative grouping. Part 1: Group versus individual problem-solving. *American Journal of Physics, 60*(7), 627-636.

Heller, P., & Hollabaugh, M. (1992). Teaching problem solving through cooperative grouping. Part 2: Designing problems and structuring groups. *American Journal of Physics, 60*(7), 637-644.

Heller, K., & Heller, P. (1995). *The competent problem solver, a strategy for solving problems in physics, calculus version* (2nd ed.). Minneapolis, MN: McGraw-Hill.

Hsu, L., & Heller, K. (2009). Computer problem solving coaches. *Proceedings of the NARST 2009 Annual Meeting.*

Hunter, P. W. (2000). The use of a computer-assisted personalized approach in a large- enrollment general chemistry course. *University Chemistry Education, 4*(2), 39-44.

Kashy, E., Sherrill, B. M., Tsai, Y., Thaler, D., Weinshank, D., Engelmann, M., & Morissey, D. J. (1993). CAPA, an integrated computer-assisted personalized assignment system. *American Journal of Physics, 61,* 1124-1130.

Kashy, E. Gaff, S. J., Pawley, N. H., Stretch, W. L., Wolfe, S. L., Morissey, D. J., & Tsai, Y. (1995). Conceptual questions in computer assisted assignments. *American Journal of Physics, 63,* 1000-1005.

Kashy, E., Thoennessen, M., Tsai, Y., Davis, N. E., & Wolfe, S. L. (1998). Using networked tools to promote student success in large classes. *Journal of Engineering Education, 87,* 385-390.

Kashy, D. A., Albertelli, G., Kashy, E., & Thoennessen, M. (2001). Teaching with ALN technology: Benefits and costs. *Journal of Engineering Education, 90*(4).

Kashy, D. A., Albertelli, G., Bauer, W., Kashy, E., & Thoennessen, M. (2003). Influence of non-moderated and moderated discussion sites on student success. *Journal of Asynchronous Learning Networks, 7*(1).

Kohl, P., Rosengrant, D., & Finkelstein, N. D. (2007). Strongly and weakly approaches to teaching multiple representation use in physics. *Physical Review Special Topics- Physics Education Research, 3*(010108), 1-10.

Kohl, P., Kuo, V., & Ruskell, T. (2008). Documenting the conversion from traditional to studio physics formats at the Colorado School of Mines: Process and early results. *Physics Education Research Conference,* 1064, 135-138, July 23-24, Edmonton, Canada.

Kohl, P., & Finkelstein, N. (2008). Patterns of multiple representation use by experts and novices during physics problem solving. *Physical Review Special Topics-Physics Education Research, 010111,*(1-13).

Kortemeyer, G., & Bauer, W. (1999). Multimedia collaborative content creation (mc3). The MSU LectureOnline System. *Journal of Engineering Education, 88*(4), 405.

Kortemeyer, G., Hall, M., Parker, J., Minai-Bidgoli, B., Albertelli II, G., Bauer, W., & Kashy, E. (2005). Effective feedback to the instructor from on-line homework. *JALN, 9*(2), 19-28.

Kortemeyer, G., Kashy, E., Benonson, W., & Bauer, W. (2008). Experiences using the open- source learning content management and assessment system LON-CAPA in introductory physics courses. American Journal of Physics, 76(4&5), 438-444.

Kortemeyer, G., Kashy, E., Benonson, W., & Bauer, W. (2008). Experiences using the open- source learning content management and assessment system LON-CAPA in introductory physics courses. *American Journal of Physics, 76*(4&5), 438-444.

Kortemeyer, G. (2009). Gender differences in the use of an online homework system in an introductory physics course. *Physical Review Special Topics-Physics Education Research, 5*(010107), 1-8.

Kowalski, F., Gok, T., & Kowalski, S. (2009). Using Tablet PCs to strengthen problem- solving skills in an upper-level engineering physics course, *39th ASEE/IEEE Frontiers in Education Conference*, October 18- 21, 2009, San Antonio, TX.

Kozma, R. B., & Russell, J. (1997). Multimedia and understanding: Expert and novice responses to different representations of chemical phenomena, *Journal Research in Science Teaching, 34,* 949.

Kozma, R. B. (2003). The material features of multiple representations and their cognitive and social affordances for science understanding. *Learning Instruction*, *13*, 205.

Larkin, J. H. (1979). Processing information for effective problem solving. *Engineering Education, 70*(3), 285-288.

Larkin, J. H., & Reif, F. (1979). Understanding and teaching problem-solving in physics. *European Journal of Science Education, 1*(2), 191-203.

Larkin, J. H., McDermott, J., Simon, D. P., & Simon, H. A. (1980). Model of competence in solving physics problems. *Cognitive Science*, *4*, 317-345.

Larkin, J. H. (1981). Enriching formal knowledge: A model for learning to solve textbook physics problems. *Cognitive skills and their acquisition,* 311-334.

Loucks, S. E. (2007). *Introductory physics with algebra: Mastering problem-solving.* US: John Wiley & Sons.

Mayer, R. E. (2008). *Learning and Instruction.* Upper Saddle River, NJ: Prentice Hall.

Mazur, E. (1997). *Peer Instruction.* Upper Saddle River, NJ: Prentice-Hall.

McDermott, L. C. (1991). Millikan Lecture 1990: What we teach and what is learned closing the gap. *American Journal of Physics, 59,* 301–315.

McDermott, L. C., & Redish, E. F. (1999). Resource letter: PER-1:Physics education research. *American Journal of Physics, 67,* 755-767.

Mendicino, M., Razzaq, L., & Heffernan, N. T. (2009). A comparison of traditional homework to computer-supported homework. *Journal of Research on Technology in Education, 41*(3), 331-359.

Mestre, J. P. (2001). Implication of research on learning. *Physics Education, 36*(1), 44-51.

Morrissey, D. J. Kashy, E., & Tsai, I. (1995). Using computer assisted personalized assignments for freshman chemistry. *Journal of Chemical Education, 72*(2), 141-146.

Newell, A., & Simon, H. A. (1972). *Human problem solving.* New Jersey: Prentice Hall.

Pol, H. (2005). Solving physics problems with the help of computer-assisted instruction. *International Journal of Science Education, 27*(4), 451-469.

Polya, G. (1945). *How to solve it.* New Jersey: Princeton University Press.

Redish, E. F., Scherr, R. E., & Tuminaro, J. (2006). Reverse-Engineering the solution of a simple physics problem: Why learning physics is harder than it looks. *The Physics Teacher, 44,* 293-300.

Reif, F., Larkin, J. H., & Brackett, G. C. (1976). Teaching general learning and problem- solving skills. *American Journal of Physics, 44*(3), 212-217.

Reif, F., & Heller, J. I. (1982). Knowledge structures and problem solving in physics. *Educational Psychologist, 17*(2), 102-127.

Reif, F., & Allen, S. (1992). Cognition for interpreting scientific concepts. *Cognitive and Instruction, 9*, 1.

Reif, F. (1995). Millikan Lecture 1994: Understanding and teaching important scientific thought process. *American Journal of Physics*, *59*, 891.

Savage M., & Williams, J. (1990). *Mechanics in action-modelling and practical investigations.* Cambridge: Cambridge University Press.

Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. *Cognitive Science, 12,* 257-285.

Thoenessen, M., & Harrison, M. (1996). Computer-assisted assignments in a large physics class computers. *Computer and Education, 27,* 141-147.

Titus, A., Martin, L., & Beichner, R. (1998). Web-based testing in physics education: Methods and opportunities. *Comput. Phys. 12,* 117-125.

Tóth, Z., & Sebestyén, A. (2009). Relationship between students' knowledge structure and problem-solving strategy in stoichiometric problems based on the chemical equation. *Eurasian J. Phys. Chem. Educ. 1*(1), 8-20.

Tuminaro, J., & Redish, F. (2007). Elements of a cognitive model of physics problem- solving: Epistemic games. *Physical Review Special Topics-Physics Education Research, 3*(020101), 1-22.

Van Heuvelen, A. (1991). Learning to think like a physicist: a review of research-based instructional strategies. *American Journal of Physics, 59,* 891-897.

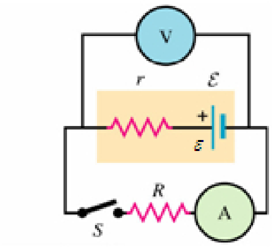
Walsh, N., Robert, H., Bowe, B. (2007). Phenomenographic study of students' problem solving approaches in physics. *Physical Review Special Topics-Physics Education Research, 3*(020108), 1-12.

Yerushalmi, E., & Magen, E. (2006). Same old problem, new name? Alerting students to the nature of the problem-solving process. *Physics Education, 41*(2), 161-167.

Appendix: Integrated Problem Solving Strategy Steps

Problem

When switch S is open, the voltmeter (V) reads 3.08V. When the switch is closed, the voltmeter reading drops to 2.97V and the ammeter (A) reads 1.65A?



a) Find the emf, the internal resistance of the battery, r, and the circuit resistance, R. Assume that the two meters are ideal so that they do not affect the circuit.

b) What is the power output by the battery to the rest of the circuit?

I

Step 1:Identifying the Fundamental Principles

1. What are the fundamental principles related to given problem?

Click on all correct answers, then click "Done"

○ Electric Field	○ Linear Charge Density
○ Gauss's Law	○ Coulomb's Law
○ Magnetic Force	○ Newton's Law
√ Ohm Law	√ Power
○ Ampere's Law	○ Lenz's Law

DONE

II

Step 2: Solving (I)

i.) Simplicity the problem situation by describing it with a diagram or a sketch in terms of physical objects and essential physical quantities. (If it is possible, you can do and show it)

ii.) Restate what you want to find by naming specific mathematical quantities.

Click on all correct answers, then click "Done"

- ◯ Magnetic Field
- ◯ Velocity
- (√) Power
- (√) Circuit Resistance
- ◯ Capacitance
- ◯ Electric Field
- (√) EMF
- (√) Internal Resistance

DONE

III

Step 2: Solving (II)

Fundamental Paramaters

V_R ; V ; R ; V_r ; ε
I_r ; $P_{battery}$; $V_{battery}$

Mathematical Calculation Signs

$(-x\vec{i}+y\vec{j})$; $\times$; $\vec{x}$; $\frac{dx}{dy}$; $+$; $-$; $d\vec{x}$
$\frac{x}{y}$; $(x^2+y^2)^{3/2}$; (x/y) ; x_y ; $\sqrt{x}$

I	Circuit Resistance	__=__ __=__ __		DONE
II	EMF	__= __ - __=__ - __		DONE
III	Internal Resistance	__=__=__		DONE
IV	Power	__=__ __=__ __		DONE

Hint 1: Assume that two meters are ideal so that they do not affect do not affect the circuit.
Hint 2: When switch is open, there is no current flow. So $V=\varepsilon$ The voltmeter reads the $emf \rightarrow \varepsilon = 3.08V$

Result

$R = 1.8\Omega$ $V_r = 0.1V$
$r = 0.067\Omega$ $P = 4.9W$

IV

Step 3: Checking

i) Has all wanted information been found?	√
ii) Are answers expressed in terms of known quantities?	√
iii) Are units, signs or directions in equations consistent?	√
iv) Are both magnitudes and directions of vectors specified?	√
v) Are answers consistent with special cases or with expected functional dependence?	√
vi) Are answers consistent with those obtained by another solution method?	√
vii) Are answers and solution as clear and simple as possible?	√
viii) Are answers in general algebraic form?	√

CONFIRM

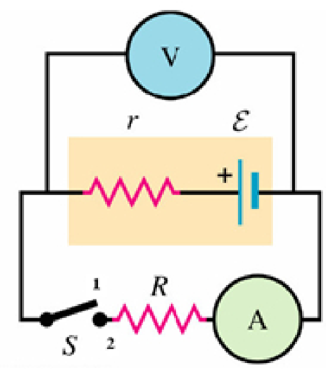
V

Solution of the problem

I. Identifying the Fundamental Principles

I. Ohm's Law   II. Power

II. Solving



a) When switch is open (1), there is no current flow.

So, $V = \varepsilon$. The voltmeter reads the emf $\rightarrow \varepsilon = 3.08V$

When switch is closed (2),

$V_R = V$ from voltmeter $R = \frac{V_R}{I} = \frac{2.97}{1.65A} = 1.8\Omega$

$\varepsilon - V = V_r = 3.08V - 2.97V = 0.11V$

r & R are in series $I_r = 1.65A$

internal resistance $r = \frac{V_r}{I_r} = \frac{0.11V}{1.65A} = 0.067\,\Omega$

b) $P_{battery} = I_{battery}V = (1.65A)(2.97V) = 4.9W$

III. Checking

$R = 1.8\Omega;$ $V_r = 0.11V$

$r = 0.067\,\Omega$ $P = 4.9W$