THE INFLUENCE OF WEB-BASED HOMEWORK ON QUANTITATIVE PROBLEM–SOLVING IN A UNIVERSITY PHYSICS CLASS

Homework is often assigned in physics classes to facilitate student learning. This study reports on the effect web-based homework has on student problem-solving and makes a comparison to the use of traditional paper-pencil homework. The students in an introductory calculus-based physics course were split into two homework groups: web-based and traditional. At mid-semester the groups switched homework types. Nine students participated in weekly, videotaped problem-solving interviews. From the analysis of this data, problem-solving characterizations of students using web-based and traditional homework were inferred. Within either homework group a student’s problem-solving strategy could be classified as either Thinker or Guesser. Thinkers had problem-solving strategies resembling those of Ph.D. physicists. Guessers had novice problem-solving behaviors. Differences were found to exist within the problem-solving categories depending upon which type of homework was being completed. In addition, when the homework groups switched, some students were found to switch their problem-solving behaviors from Thinker to Guesser or vice versa. The interpretation of the results of this study implies that the use of web-based homework hindered metacognitive behaviors.

Andrea M. Pascarella, Department of Physics, University of Northern Iowa, Cedar Falls, IA 50614-0150

Lecture, recitation, and laboratory are all integral elements to a student’s effort to learn physics. All three elements involve classroom time, which on its own, is not sufficient for most students to learn physics. However, outside class, the majority of students will not take the initiative to read the textbook and work through problems. The solution has been to send students home each week with a homework assignment to be collected and graded. Among members of the physics community, the prevailing ideology behind homework is that by practicing problem-solving a student will become a better problem-solver. To be a better problem-solver, however, it is necessary for the student to have some grasp of the underlying physics concepts.

In the last decade, a variety of efforts have been undertaken to put physics homework online making it web-based. These efforts include WebAssign, CAPA (Computer-Assisted Personalized Approach), and UT Homework Service. Research into the effects of web-based homework systems has been contradictory, sparse, and in some cases, not very systematic. Bonham, Beichner, and Deardorff (2001 & 2003) reported that students who used traditional hand-written homework experienced no significant differences in learning gains when compared to students using the WebAssign system. Studies carried out by the CAPA development team concluded that online homework had a significant, positive effect on student learning (Kashy, Sherrill, Tsai, Weinshank, Englemann, & Morrissey, 1993; Kashy, Morrissey, Tsai, & Wolfe, 1995; Morrisey, Kashy, & Tsai, 1995; Kashy, Thoennessen, Tsai, Davis, & Wolfe, 1998). In addition, the CAPA development team claimed that CAPA promoted the development of advanced problem-solving skills. However, Bonham, et. al. found no significant differences in the exam solutions of a group of students using online homework and another group who employed traditional homework. The incongruity among results of studies on the effectiveness of online homework warranted further investigation.

A systematic study of web-based homework that addresses the above issues was needed. This paper focuses on only one component of a larger study and addresses the following questions.

- What behaviors did students display when solving quantitative problems using web-based homework? What behaviors did students display when solving traditional paper-pencil homework?
- How were the above behaviors affected by the feedback available from each homework format?
- In which ways were students' problem-solving behaviors affected when they changed to a different homework format (e.g. from traditional to web-based and vice versa)?

Theoretical Underpinnings

Applying constructivist learning theory to a physics course dictates that students must build their own understanding of the course material. An oft stated goal of physics instruction is that students learn how "to 'do' physics in an expert way" (Redish, 1994, p.4). Reif and Scott (1999) echo this sentiment in their belief that, among other things, "instruction should enable students… to become good problem solvers and independent learners" (p.2). This implies that students should mature from novice to more expert-like problem solvers. In this sense, a problem is the kind of task typically found at the end of a chapter in an introductory physics textbook. These quantitative problems present students with specified goals, such as, "find *x*," and the students must develop and carry out a plan that will take them from an initial problem analysis to the solution (Reif, 1995).

Stereotypical poor problem solvers, called novices, lack any logical strategy for reaching the solution. Novices focus on the surface features of the problem instead of the underlying physics principles (Chi, Feltovich, & Glaser, 1981; Hardimanm Dufresne, & Mestre, 1989). They will use these features to find what they view to be an appropriate equation to use, typically one that contains the unknown variable. Novices will then proceed by plugging in whatever values were given in the problem description before trying to solve for the unknown. If, after plugging in the given quantities, there is an additional unknown, the novice solvers will look for another equation, containing the new unknown. Then they try to solve for that unknown so they may plug it back into their original equation. This strategy, referred to as "working backward," Can be likened to trying to find one's way through a maze by starting at the finish, where one frequently reaches a dead end and must go back and begin again (Larkin, McDermott, Simon, & Simon, 1980).

Experts' knowledge is highly organized and connected, which allows them to typically work in a systematic manner until they have an answer. After reading a problem description, expert problem-solvers progress by making qualitative analyses of that problem. These analyses consist of categorizing the problem on the basis of the physical principles involved and developing an explicit solution method based upon these same principles (Chi, et. al., 1981). Then, experts will use a mathematical representation of the problem to obtain a solution (Larkin, & Reif, 1979). As a final step, expert problem solvers will evaluate the reasonableness of their answer by asking if the answer makes sense.

A common belief held by members of the physics community is that students develop their problem-solving skills by actively engaging in activities that require problem-solving. This is the fundamental reason behind assigning problems for homework. The advent of web-based homework systems has provided students with a new means of engaging in problem-solving.

From an administrative point of view, web-based homework systems are easy to use, timesaving and convenient. In addition, problems are coded to randomize certain necessary quantities, so that each student receives a unique assignment with unique solutions. Thus, students cannot blindly copy a classmate's solutions. Furthermore, students can access their homework assignments over the Internet, which allows them freedom in deciding when and where to work on their assignments. Finally, the immediate feedback and the ability to make multiple attempts at a correct answer are considered to be important advantages that computerized homework has over traditional paper-pencil homework.

Some aspects of web-based homework systems may not be beneficial. The use of corrective, yes/no, feedback informs students as to whether or not they have obtained the right answer but it does not advise them as to why incorrect answers are wrong. Occasionally hints are programmed into some problems but they are often too generic to be helpful. Quality feedback is "designed to stimulate correction of errors through a thoughtful approach to them in relation to the original learning relevant to the task" (Black, & Wiliam, 1998, p. 36). It is generally believed that for feedback to be useful it needs to provide information on the gap between the student's actual performance and the student's ideal performance.

Because web-based homework systems grade only the answer, it places importance on the final result, not the process used to obtain the solution. Futhermore, the ability to enter a solution multiple times combined with little or no instructive feedback can lead students to adopt a trial-and-error strategy. Limiting the feedback only to corrective feedback shifts the focus away from the goal to task completion (Ilgen, & Davis, 2000; Kluger, & DeNisi, 1996). Often in these situations, the student will "experiment with successful task strategies resulting in poorer task performance" (Kluger, & DeNisi, 1996, p. 263). In these situations, feedback may have a negative effect on learning because the trail-and-error strategy shifts the focus of the activity to getting the correct response and is often no longer on knowing why responses are correct.

In this paper, three different relationships are explored. First, students' behaviors while they worked on either traditional paper-pencil or web-based are studied and compared. Second, the effect of immediate feedback on web-based homework users is examined. Lastly, the effect of a different homework format on students' problem-solving behaviors is explored.

Research Design

This study was carried out during the fall of 2001 in a calculus-based introductory physics course ($N \approx 515$) at a large research university in the Rocky Mountains. The entire class was split into two treatment groups, a CAPA group ($N \approx 265$) and a traditional paper-pencil homework group ($N \approx 250$), based upon recitation sections. Students did not know which section they were registering for ahead of time. The two homework groups were required to complete the same weekly homework assignments. Members of the CAPA group had to submit their assignments online, which allowed them to get instant feedback and provided them with multiple attempts to submit a correct answer. On the other hand, members of the traditional homework group had to turn in their written assignments for grading; they were prevented from having any access to the solutions until after their assignment was turned in. At midterm, the two groups switched; the CAPA group adopted traditional homework and the traditional homework group adopted CAPA.

Videotaped problem-solving interviews were used to gather the data necessary to address the research questions posed above. During these interviews students were required to think aloud while working on their weekly homework assignment. The interviewer was not allowed to intervene and could only interact with the students to obtain any needed clarifications.

The interview sample was non-random and consisted of nine students. They were chosen from a set of students who volunteered based solely on how well their availability matched the availability of the interviewer. The interview group contained 3 females (F1 – 3) and 6 males (M1 – M6). Every student was a freshman; two had never taken a physics class before. Seven students were concurrently taking Calculus I, while two students enrolled in Calculus III. Two students held jobs. All students were taking between 12 and 18 credit hours. Seven students had high school GPAs within the A range, while the remaining two had high school GPAs between B- and B+. These students earned three A's, 5 B's and one C in this physics course.

The sample was too small to be representative of the entire class. Therefore, the generalizations and conclusions that are discussed in this paper are limited in their scope and applicability to other situations. This may be seen as a disadvantage, however, it would have been impossible to obtain data as rich as what was obtained with the videotaped problem-solving interviews from more quantitative means.

Data Analysis and Findings

The video data were transcribed and analyzed using ethnographic techniques to identify trends in the process each student employed to move from a quantitative question statement to an answer. Each student's actions, along with the number of observed occurrences of those actions, were recorded. If a student performed certain tasks in at least 50% of the problems, those actions were used to characterize that student. From these characterizations a generalized problem-solving strategy was inferred for each student. In addition, the final interview conducted with the students served as a wrap-up session in which the students were asked to discuss how they solved problems using each homework method. The methods that the students reported using were compared to the analysis of the video data. The generalized problem-solving strategies for each student were then considered as a whole and trends were used to develop global problem-solving strategies for CAPA and traditional homework users.

Four types of quantitative problem solvers emerged from this data – CAPA Thinkers, Traditional Thinkers, CAPA Guessers, and Traditional Guessers.

CAPA Thinkers read the question, and draw and label a picture. They tend to re-read the question to remind themselves of what unknown they need to solve for. If the problem contains multiple steps they will plan a rough outline of their solution. For example, they might recognize that they need to find X so they can get Y, which is necessary for obtaining Z, which is what the question asked for. They will then apply the appropriate concepts to get equations that describe the physical situation. After performing the necessary algebra, with variables, they will substitute their unknowns and solve. CAPA Thinkers will immediately enter their answers into CAPA to see if they are correct. If they are correct, they will move on to the next question. If they get a "No" they tend to recalculate their answer, check their algebra, or check their initial equations.

Traditional Thinkers generally follow the same method as CAPA Thinkers until they have obtained an answer. At this point they do not have the ability to check with the computer to see if their answers are correct. Instead, the Traditional Thinker will evaluate the reasonableness of their answers on their own. They ask themselves if the solution could be possible and they confirm their methods against their understanding of physics.

CAPA Guessers will often jump right into their lecture notes after reading the question. They look for equations that might possibly pertain to the problem (these are generally identified to be any equation that contains the unknown). They will solve the equation that they found for the unknown by first substituting their known quantities into the equations and then doing the algebra right into their calculators. They tend to enter their answers right into the computer from the calculator screen. If they get a "Yes", they immediately move to the next question. When they get a "No", they will check their math. If this doesn't yield a different answer to try, they will go back and check their initial equations. This is generally accomplished in one of two ways. First, they will try to go back to their notebooks and look for other equations that they can try. Secondly, they may compare the problem they are trying to solve to the derivation of the formula they tried to use. If they can note any differences they may adjust the original equation and try that.

Traditional Guessers tend to proceed through a problem in a manner similar to that of a CAPA Guesser. The difference is that once a Traditional Guesser obtains an answer, they do not know if it is right or not. They will often stop working on the problem once they have an answer and start the next question.

Halfway through the semester the groups switched homework types (CAPA students started to do traditional homework and vice versa). It was expected that students who were initially CAPA Thinkers would be Traditional Thinkers after the change and vice versa. It was also thought that similar changes would occur among the Guessers. This was indeed seen among many of the interview subjects. F3 and M3 both went from being CAPA Thinkers to Traditional Thinkers. M1 and M2 made a transformation from CAPA Guessers to Traditional Guessers.

But it was not expected that students would make a switch into a completely different category (Thinker to Guesser or vice versa). Students who jumped into a category that was not equivalent to their original classification were classified as “Switchers”. M4, a CAPA Guesser, became more like a Traditional Thinker. In about 5 weeks of taping M4 as he worked on CAPA he correctly completed one problem. When doing problems he would have trouble starting; he would search for equations and not understand how to apply them. Often he would get stuck early on and skip to the next problem. When he became a traditional homework student his work became more organized and he would reflect on a problem and struggle to understand it instead of just getting a correct answer and moving on. He remarked, “I like the written homework because it’s, just uh, much more self-explained, um, and you can see exactly how and why the problem is done that way.”

M5, a Traditional Thinker became a CAPA Guesser. M5 would evaluate his work when doing traditional homework. At the end of each problem he would ask himself whether or not his answer seemed reasonable. When he started completing the web-based homework it became apparent that he was relying on the computer for that feedback. His work became sloppy and his problem-solving behavior reflected a CAPA Guesser rather than a CAPA Thinker. In reference to his method during the second half of the semester, when using CAPA, M5 said the following.

> I’ve been known to do them directly into my calculator, you know, and I’ll try, I’ll average 4 wrong tries, if I’m doing it straight into my calculator and it looks like an easy problem then I’ll put it in and be like, “Oh, I forgot the ½. Oh, I forgot to square it, that should have been negative, oh, okay, now it works” and then I’ll get it right and move on. And I don’t think, I never wrote it out on paper. I never wrote the real thing out.

F1 and F2’s started the semester using strategies that more closely resembled those of Traditional Thinkers than Traditional Guessers. However, after they changed homework types, their problem-solving began to more closely resemble that of CAPA Guessers. F1 describes their method with CAPA in this way: “This time we were just kind of like, let’s try it and see if it works, we’ll plug it in and if it doesn’t work we’ll try something else.”

Discussion

Major differences between the CAPA and traditional homework are apparent from the four quantitative problem-solving characterizations. CAPA Guessers and Traditional Guessers employ “equation grabbing,” a working-backwards technique seen among novice problem-solvers. Guessers search through their notes for an appropriate equation to use and try it. The difference between traditional homework and CAPA for the Guessers is that when CAPA notifies the students that they are incorrect, it is informing the Guessers that they are not yet using the right equation. CAPA Guessers will proceed by continuing their search for the correct equation to use. An incorrect answer simply indicates another one of many “false starts” that novices tend to make. Traditional Guessers do not have this feedback available to them so they simply move on to the next problem.

Thinkers approach CAPA and traditional homework problems in a manner comparable to expert problem solvers. These students approach a problem by identifying which physics concepts are needed to reach a solution. They then design their solution accordingly. Traditional Thinkers evaluate the reasonableness of their solutions, similar to experts. On the other hand, CAPA Thinkers do not evaluate their answer. They immediately enter their answers into the computer, which allows the computer to return a “Yes” or a “No”, This implies that the computer is doing the evaluation for the students and is hindering metacognitive activities in the Thinkers.

It was hypothesized that at mid-semester, when the groups changed homework types, that Thinkers would remain Thinkers and Guessers would remain Guessers. However, this was not entirely seen in the data. Some Traditional Thinkers became CAPA Guessers and vice versa. These students were called “Switchers.” The data on Switchers seems to indicate that CAPA promotes Guessing or the use of novice problem-solving strategies. In addition, this data appears to indicate that traditional homework promotes the use of Traditional Thinking or expert problem-solving strategies. It may be inferred from this data that Traditional homework promotes metacognition, while CAPA hinders it.

For CAPA to be a valuable learning tool, it needs to encourage students to be Traditional Thinkers on the quantitative problems. In other words, CAPA should encourage students to evaluate the reasonableness of their solutions. Perhaps, web-based homework is not meeting this goal because the feedback, which is limited to corrective yes/no feedback, is not the most effective. Based on the feedback literature, it is known that corrective feedback combined with multiple tries can lead students to adapt a trial-and-error strategy with a focus on completing the assignment versus learning the fundamental principles underlying the material. This focus on completing the assignment is seen in the methods employed by the CAPA Guessers. One way to help achieve the goal of making web-based homework systems more valuable learning tools would be to cut down the number of tries each student has to get the correct answer. As M5 said, “In fact, with less tries, it would probably make me write more things down and do the problems more carefully so that I didn't waste them." And M2 expressed that "if you need them all you really aren't understanding it anyway." More tries may just encourage CAPA Guessers.

Another way to help achieve the goal of making web-based homework systems more valuable learning tools would be to penalize a student's grade for each incorrect answer. In other words, a student would be able to earn full credit for a problem if the answer was obtained on the first try. On subsequent attempts to obtain the correct answer, the student would be penalized by a reduction in the number of points earned for a correct answer. This may discourage trial-and-error methods and encourage metacognitive processes, because students' grades are negatively affected by repeated attempts to find the correct answer.

Another useful addition to web-based homework may be to link the assignments to online tutorials. For feedback to be useful it needs to provide information on the gap between the student's actual performances and the student's ideal performance. If students were to get a question wrong they would be directed to a tutorial that focuses on the underlying concepts involved in the problem and then help the students develop these ideas into an appropriate solution. This type of interactive problem is currently being developed at the University of Illinois, Urbana-Champaign (Stelzer, & Gladding, 2001) and has been developed as CyberTutor at MIT (Prichard, Morote, & Kokorowski, 2002).

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