

Is Conceptual Understanding Compromised By A Problem-Solving Emphasis In An Introductory Physics Course?

J. Ridenour^{*}, G. Feldman^{*}, R. Teodorescu^{*}, L. Medsker^{*,†} and N. Benmouna[‡]

^{*} *Department of Physics, The George Washington University, Washington, DC 20052*

[†] *Department of Physics and Astronomy, Siena College, Loudonville, NY 12211*

[‡] *Department of Physics, Engineering and Geosciences, Montgomery College, Rockville, MD 20850*

Abstract. Developing competency in problem solving and enhancing conceptual understanding are primary objectives in introductory physics, and many techniques and tools are available to help instructors achieve them. Pedagogically, we use an easy-to-implement intervention, the ACCESS protocol, to develop and assess problem-solving skills in our SCALE-UP classroom environment for algebra-based physics. Based on our research and teaching experience, an important question has emerged: while primarily targeting improvements in problem-solving and cognitive development, is it necessary that conceptual understanding be compromised? To address this question, we gathered and analyzed information about student abilities, backgrounds, and instructional preferences. We report on our progress and give insights into matching the instructional tools to student profiles in order to achieve optimal learning in group-based active learning. The ultimate goal of our work is to integrate individual student learning needs into a pedagogy that moves students closer to expert-like status in problem solving.

Keywords: problem solving, active learning, collaborative group learning, conceptual understanding, SCALE-UP.

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INTRODUCTION

We are currently developing and testing an easy-to-implement intervention, the ACCESS protocol [1], which develops students' problem-solving skills in introductory algebra-based physics, using the proven SCALE-UP pedagogy [2] pioneered at NC State University. The cultivation and sharpening of the individual component skills needed for the problem-solving process have been emphasized over the comprehensive treatment of physics content. Focusing specifically on the gap in expert-novice problem-solving behavior, the novel feature of this project is the introduction of this new problem-solving protocol (ACCESS) within the SCALE-UP pedagogy. Structured around a series of specific cognitive processes in which the students must engage when solving problems, our protocol helps students develop the component skills of classifying the problem, representing the data, designing a strategy, executing a solution, evaluating the answer and reflecting on the learning. These stages are summarized in Fig. 1, and the students are trained in this manner from the start of the semester. The ACCESS protocol is built upon Marzano's New Taxonomy of Educational Objectives [3], which updates fifty years of learning research since Bloom's Taxonomy [4] and provides a new "Thinking Skills" hierarchy that organizes cognitive and meta-cognitive processes along with the domains of declarative and procedural knowledge in a

comprehensive framework. To develop the individual component skills of the protocol in a step-by-step fashion, the students are exposed to carefully selected traditional and PER-based problems and exercises that are classified according to the thinking skills they cultivate.

Problem-Solving Protocol

- A** Assess the problem
- C** Create a drawing
- C** Conceptualize the strategy
- E** Execute the solution
- S** Scrutinize your results
- S** Sum up your learning

FIGURE 1. The six basic stages of the ACCESS protocol.

LEARNING METHODS/ASSESSMENTS

We have inferred from prior experience with problem-solving approaches in introductory algebra-based physics the possibility of having to sacrifice the amount of conceptual learning to accommodate the

time needed for students to learn deep problem-solving skills. During Summer 2011, we developed a hybrid approach that made the problem-solving aspect more efficient and that was more selective in the conceptual aspect of the course. To accommodate the targeted measurements we had identified, we re-structured the method of grouping students to allow measurement of the effect of working in different types of groups on individual student success rates in conceptual learning and problem-solving skill building. Force Concept Inventory (FCI) [5] gains were considered important measures of conceptual learning; we would use these results to gauge progress in our experimental course (with ACCESS) as compared to traditional algebra-based classes or other SCALE-UP classes (without ACCESS). Thus, many of our research questions aim to clarify the conditions under which significant problem-solving skills can be acquired without sacrificing conceptual learning. The disaggregation of the effects of different variables we had identified earlier inspired us to record and measure student characteristics such as prior ability in physics and mathematics, scientific intelligence, gender, attitude toward science, motivation for taking the course, and the ability to learn in groups. Standard instruments such as the Force Concept Inventory (FCI) [5], the Lawson Classroom Test of Scientific Reasoning [6], and the Colorado Learning Attitudes About Science Survey (CLASS) [7] were used, and we developed our own surveys when needed.

Experimental Setup At GW

In the Fall 2011 semester, a new expanded high-tech SCALE-UP classroom became available at GW. This increased our capacity from 36 to 81 students, with nine round tables (7 feet in diameter) that each accommodates three groups of three students. During a class day, each student in a group has a specific role (manager, recorder, or skeptic) when working on all group activities (ponderables and tangibles) for that day. The roles are then rotated in subsequent class days, such that each student gets a chance to function in each of the three roles several times during the semester. This ensures that one student does not do all the talking or the work, and that another student does not remain silent throughout the semester. Thus we were implementing the standard SCALE-UP method, with which we had become proficient in previous semesters. To this we added our ACCESS problem-solving protocol, which had already been practiced during prior years in the context of the regular lecture/lab course.

RESEARCH QUESTIONS

We have identified a series of particular questions that we would like to address in our research:

- 1) What do students choose to use when they are not required to use a problem-solving protocol?
- 2) Can students show a logical solution if not required to follow a strict problem-solving plan?
- 3) Can students get a problem right without a plan?
- 4) Do students who get the problems right when working in groups also get them right when working individually?
- 5) Do groups who get correct solutions to problems write systematic solutions?
- 6) What is the optimal balance between problem-solving and conceptual learning activities?

This paper will focus primarily on points 1, 2 and 6 of this list of research questions.

Preliminary Results From GW

After a large amount of data was collected in the new SCALE-UP classroom at George Washington University (GW) in Fall 2011, the focus during the Spring 2012 semester was on analyzing these data. Much of the work involved careful grading of quizzes, exams, homework assignments, and group work using rubrics for consistent treatment of students' products. The data analysis will continue through the summer, and further measurements in the upcoming Fall 2012 semester will seek to clarify further issues that we identify and to verify some of our important conclusions.

Our preliminary research results have been focused on addressing research questions 1 and 2 listed above. For example, we have examined students' self-assessments about problem-solving skills and confidence in problem solving. This was based on a self-reflection survey given near the end of the semester asking students to rate their skills and confidence from the early days of the semester and at the end. The ratings were based on a Likert scale (0-5), and then the relative shift from start to finish was determined by the difference. The results of this self-assessment are shown in Fig. 2 below, and the indications are that most students felt that they had made positive (and in some cases, significant) gains in both skills and confidence by the end of the semester.

At the mid-point of the semester, after training in ACCESS had been completed, we asked the students to decide on their preferred "philosophy" for problem solving and we divided them into three categories: those who committed to using ACCESS exclusively, those who never would use ACCESS at all, and a

hybrid group whose members would make decisions on a problem-by-problem basis about when and when not to use ACCESS. Table 1 below shows, from the self-reflection survey of each group, the gains for skill in problem solving as well as gains for confidence in problem solving.

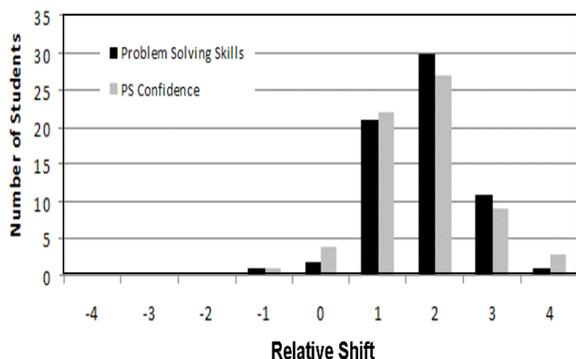


FIGURE 2. Results of students’ self-reflection survey about problem-solving skills and confidence in the Fall 2011 semester at GW. Positive shifts denote improvement.

TABLE 1. Gains in problem-solving skills and problem-solving confidence resulting from a self-reflection survey of each group.

Group Affiliation	Problem-Solving Skill	Problem-Solving Confidence
ACCESS	2.08	1.69
Non-ACCESS	1.48	1.22
Hybrid	1.79	1.89

The results indicate that all students felt their problem-solving skills had improved and that they were more confident in solving problems by the end of the semester. Students strictly using the ACCESS problem-solving method clearly showed higher gains in problem-solving skills and in confidence than those students not using ACCESS. Students using ACCESS also had higher gains in problem-solving skills than the hybrid group; however, it is interesting to note that the hybrid group had higher gains in confidence than either the purely ACCESS or the purely Non-ACCESS students. Further work will seek to determine if the hybrid group members tend to have more confidence because they know they can choose the approach that suits them best for a particular problem.

In the same course (Fall 2011), the normalized FCI gain for the entire class was $\langle g \rangle = 0.45$ which is indicative of significant conceptual improvement. The fact that such gains were achieved suggests that the advances in problem-solving development did not

come at the expense of conceptual understanding. This was encouraging, since earlier semester trials using ACCESS that had been preparatory to this project had in fact shown only modest FCI gains.

Preliminary Results From MC

At Montgomery College, no formal SCALE-UP classroom exists, and so a predominantly collaborative environment was established in lecture/lab sections. The development of this effort has been ongoing for three academic years (2009-12). Typically, the fall semesters were used as pilots for new materials developed based on results obtained from the spring semesters which were the full implementation periods. Student learning outcomes were assessed using the FCI for conceptual gains and a rubric based on the ACCESS protocol for problem-solving skills.

The overall goal was to create a balance between enhancement of conceptual understanding and training in problem solving. This targeted research question 6 listed on the previous page. In the first year, it was found that the ACCESS protocol was very powerful in enhancing students’ problem-solving skills. However, students’ scores on the FCI were quite low. Most of the class time was spent on problem-solving practice. In the second year, more extensive conceptual practice was incorporated for the students, and therefore obviously less time was spent on problem-solving practice. The results revealed that students performed better on the conceptual understanding assessment (FCI), as seen in Fig. 3 below, but this came at a heavy price — lower scores on the problem-solving assessment were observed. It was therefore understood that a better balance was needed between conceptual practice and problem-solving practice. This was accomplished in the third year, and as shown in Fig. 3, the conceptual aspects did not suffer, thus verifying that a more equitable balance had been achieved.

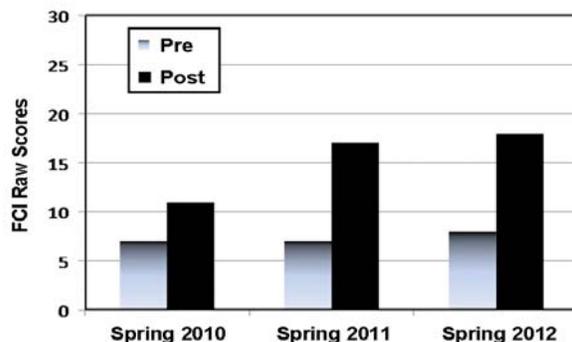


FIGURE 3. FCI pre-test and post-test scores for three Spring semesters (2010-12) at Montgomery College.

It is clear from the figure that considerable progress was made in the second and third years. The normalized FCI gains for these three pre/post-test pairs correspond to $\langle g \rangle = 0.17, 0.44$ and 0.46 , respectively, which in the last two years are comparable to the FCI gains from the GW class reported above.

The improvement of problem-solving skills over the three semesters at MC is shown in Fig. 4. The second semester (Spring 2011) had a greater emphasis on concepts, as mentioned earlier, and so the problem-solving results decreased a bit. The optimal balance was achieved in the third semester (Spring 2012), and this can be seen by comparing the results shown in Figs. 3 and 4 together.

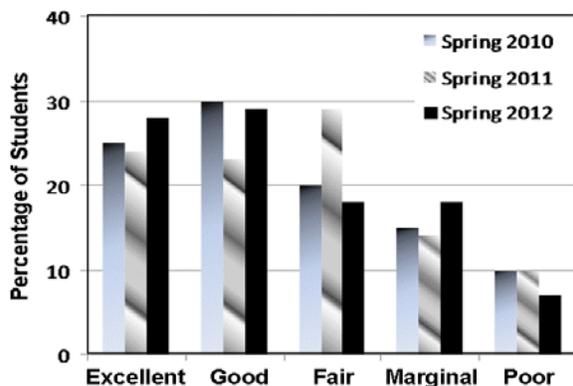


FIGURE 4. Comparison of results for problem-solving assessments for three Spring semesters (2010-12) at MC.

SUMMARY

We have been working on bridging the expert-novice gap in introductory algebra-based physics courses by incorporating the ACCESS problem-solving protocol as a framework within the context of a collaborative active-learning environment based on the SCALE-UP pedagogy. We have had parallel efforts at a large research university (George Washington University) and a local community college (Montgomery College), with rather different student populations. While substantial progress has been observed, a balance must be established between the development of problem-solving skills and the enhancement of conceptual understanding. It is possible to over-emphasize one of these aspects at the expense of the other if the curriculum is not managed carefully.

Our experience and graphical results to date indicate clear effects in the experiments to achieve balance in conceptual understanding versus learning of higher-order problem-solving skills. Further analyses

using non-parametric methods will be aimed at quantifying and clarifying these effects. The work reported here points to more specific new issues being addressed in experiments that are in progress.

In addition, experiments in the classroom with the composition of groups in the SCALE-UP environment have led to some interesting observations about skill development and confidence building when students have been required (or not required) to use ACCESS. Those students who committed themselves to the structured approach showed greater improvement in problem solving, although students who opted for a hybrid approach had more significant gains in confidence levels. The interpretation of these results is still not entirely clear, but this is certainly a factor that warrants further investigation.

This work on problem-solving skill development will continue at both institutions (GW and MC). At MC, a very recent addition was the introduction of Inquiry-Based Learning (IBL) [8] into the laboratory period. The use of IBL provides the students with many opportunities to practice both good conceptual understanding and problem-solving skills. In the coming Fall 2012 semester at GW, another major set of data will be collected from a large class (~80 students) conducted in the SCALE-UP methodology. Modifications in our delivery of this pedagogy will be motivated by the lessons learned from the completed analysis of the Fall 2011 data set. We will also include additional surveys and assessments in order to explore the other research questions posed in our earlier list.

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