Expert and Novice Use of Multiple Representations During Physics Problem Solving

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Abstract. It is generally believed that students should use multiple representations in solving certain physics problems. In this study, we interview expert and novice physicists as they solve two types of multiple representations problems: those in which multiple representations are provided for them, and those in which the students must construct their own representations. We analyze in detail the types of representations subjects use and the order and manner in which they are used. Somewhat surprisingly, both experts and novices make significant use of multiple representations. Some differences emerge: Expert use of multiple representations is more dense in time, and novices tend to move between the available representations more often. In addition, we find that an examination of multiple representation use alone is inadequate to fully characterize a problem-solving episode; one must also consider the purpose behind the use of the available representations.

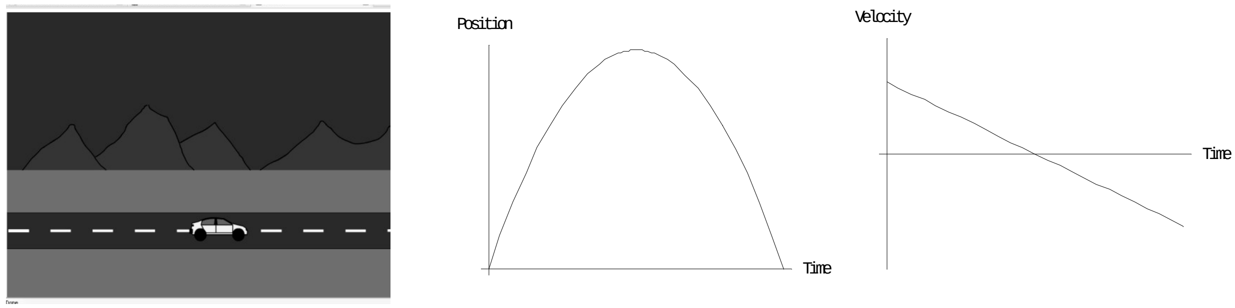
INTRODUCTION

PER has a long history of research into problem solving, especially as it pertains to physics novices (see Maloney[1] or Hsu[2] for reviews). Much of this research has investigated novice (and sometimes expert) use of representations during problem-solving episodes. "Representations" is used broadly, and can refer to whether the problem solver is representing surface features of a problem or the deeper physics.[3,4] The term can also refer to the use of multiple representations together, such as pictures, free-body diagrams, and equations. Note that in this paper, we will use the term "representations" to refer to representations on paper, as opposed to mental representations. Much of the work on multiple representation use during problem solving has focused on how to promote this use during instruction.[5,6,7,8] Some prior work exists in PER on multiple-representations problem solving at the scale of single problems,[9,10] For instance, Larkin and Simon[11] find that expert representations tend to focus on "physical" features such as energy, while novices are more likely to attend to surface features (such as shape). Outside of PER, Kozma[12] has compared chemistry experts in the workplace to novices engaged in academic tasks.

A few significant questions remain regarding the differences between expert and novice use of representations during physics problem solving. Do the major differences lie in the kinds and frequencies of representation use, or do they lie in the patterns and sequences of representation use? We might also expect there be differences in *why* experts and novices use representations. Without a clear picture of how experts and novices differ in their approaches to multiple-representation problem solving, it will be difficult to properly bridge the expert/novice gap with instruction.

In our study, we begin to address these issues in detail. We interview ten introductory physics students and five graduate students, providing novice and expert samples. In these interviews, the subjects solve a variety of problems using multiple representations in the areas of kinematics and electrostatics. We then perform a fine-grained analysis of these interviews, with the goal of characterizing the major differences and similarities between the two samples in terms of success, frequency and sequence of representation use, and purpose towards which these representations are applied.

We present two main results in this paper. First, as one would expect, the experts solve their problems in less time, often using the same set of representations as novices but in a shorter time. Surprisingly, however, the novices interviewed do not show the reluctance to use a variety of representations that one might expect. Indeed, their solutions were often more complex in terms of number of translations between representations. Second, experts differ quite noticeably from novices regarding their applications of representations, with more careful analysis and self-checking, and less weakly-directed, unplanned work. These results together allow us to begin to paint a picture of what distinguishes a novice from an expert in terms of representation use, a picture likely to have consequences for instruction.



A car starts in motion and undergoes constant acceleration in the –x direction.

FIGURE 1. Four different representations of the motion of a car. The car problems studied required students to group these representations together as appropriate.

METHODS

Five of our interviewed novices were from CU's first-semester large-lecture introductory algebra-based physics course from the fall of 2005, which we refer to as Physics 201. The other five novices were drawn from the second semester of this course in the spring of 2006, Physics 202 (a course we have described previously[8]). Our five expert problem-solvers were physics graduate students, usually in the first year or two of their program. Interviews typically lasted about an hour.

Our problem-solving interviews used two types of multiple representations problems: those in which students were provided with a variety of representations, and those in which students had to generate additional representations on their own. Students from Physics 201 solved problems of the first type. In these, which we refer to as the car problems, students were given sets of representations of the motion of a car. This included a set of graphs of position versus time, a set of graphs of velocity versus time, a set of Flash animations depicting a moving car, and a set of written descriptions of a moving car. The students were instructed to make as many groups as possible of members from the various sets; that is, they were told to select position graphs, velocity graphs, animations, and written descriptions that all corresponded to one another. They were also told that not all members of each set would be used in all groups, and that it was possible to find groups of fewer than four elements. Figure 1 shows a sample grouping of two graphs, a written description of motion, and a screenshot from a flash movie.

The 202 novices solved the five electrostatics problems seen in Ref. 8. All of these problems involved numerically calculating either a force or a charge, usually with Coulomb's law. One explicitly required the production of a free-body diagram as part of the answer, while all five (especially the fifth, or challenge problem) were made easier by drawing a picture and/or an FBD. The challenge problem involved calculating the tension in strings holding two charged, attracting balls.

The experts solved all of the problems given to the 201 and 202 novices, as well as one problem designed to be challenging. The expert problem is the pulley problem used by Larkin in Ref. 3. We will reserve analysis of this pulley problem for a long-format paper. All of the problems are located on the web.[13]

All interviews were coded in two main ways. First, we coded representation use as a function of time. We divided the interview episode into ten-second blocks and noted which of the available representations (pictures, FBDs, written language, math, movies, position graphs, velocity graphs) students made use of or reference to in each block. It was possible for more than one representation to be present in each block of time.

Second, the parts of the interviews corresponding to the solutions of the five electrostatics problems were coded in an additional way. Here, we coded for the kinds of activities students engaged in, including reading, translation, analysis, exploration, planning, implementation, and verification. We adapted the activity categories and rubric from Schoenfeld,[14] with input from the authors and a member of the CU PER group unrelated to the project. We performed interrater reliability checks for all of the codings in this paper.

We also defined a complexity parameter describing each of the coded solutions. Briefly, this parameter reflects the number of translations between representations made by a subject during a problem-solving episode. For instance, a solution that begins with a written description, moves on to a picture, then a free-body diagram, and finally mathematics, would be

TABLE 1. (right) Performance of expert and novice students on the car problems, electrostatics (E1-4), and the challenge problem. Car problem figures show the average number of correct/incorrect representation groups created. Electrostatics figures show the number of students solving each problem correctly/incorrectly.

	Car	E. 1	E. 2	E. 3	E. 4	Challenge
Expert	7.6 / 0	4 / 1	4 / 1	5 / 0	5 / 0	5 / 0
Novice	5.0 / 1.0	3 / 2	3 / 2	1 / 4	0 / 5	1 / 4

TABLE 2. (right) Measures of the representational complexity (Comp) of student solutions and of the time density of their translations between representations (Dens, translations per minute), averaged across experts (E) and novices (N). Higher Comp numbers represent more translations between representations during a solution.

	Comp, E	Comp, N	Dens, E	Dens, N
Car Probs.	5.2	7.4	4.6	3.4
Elect. 1-3	7.2	6.4	2.1	1.3
Elect. 4	6.0	10.3	2.7	2.3
Challenge	11.8	15.8	2.4	1.5

assigned a complexity of 3 representing the three shifts in representation. Should the student return to a previous representation, that shift would increase the coded complexity. A small number indicates a simple, linear sequence of representations used, while a larger number represents a more complex and iterative approach.

DATA

There are many options available for characterizing the solutions studied here. In this paper, we focus on a small subset of these options for brevity.

In Table 1, we see expert and novice performance on the problems studied. As is expected, the experts outperformed the novices on all problems, though the novices are at least partly successful on all but electrostatics problem 4.

In Table 2, we characterize the patterns of representation use present in student solutions with two parameters. The “Comp” columns display the complexity parameter, averaged over all experts and all novices for the car problems, electrostatics problems 1-3, electrostatics problem 4, and the electrostatics challenge problem. The novices show a tendency (not absolute) towards more complex solutions, in the sense that they move back and forth between representations more often (if not as quickly) over the course of their solutions.

In the “Dens” columns of Table 2, we see the average number of translations between representations per minute made by experts and novices over the course of their solutions. Experts appear to be consistently moving more quickly between the representations available. Data on the number of representations used in total (not shown) suggests that both expert and novice problems solvers were using a wide variety of representations, both in the car problems in which this was required and in the electrostatics problems where it was not. Most novices and experts used at least a picture and equations in all electrostatic problem solutions, and some used free-body diagrams as well.

In Figure 2, we consider the purposes towards which the individuals applied the representations they used. Here, we focus on the electrostatics problems in which students had to generate their own problem representations. The graphs show the fraction of the codeable time intervals occupied by each of the activities listed. The biggest differences between experts and novices appear in the Reading, Analysis, and Exploration categories. Experts spend a greater fraction of their time reading the problem, though we believe this to be an artifact of their generally shorter solution times. More significant is the time spent in Exploration by the novices. Analysis represents a directed, systematic attempt to more fully understand the problem. Analysis generally is explicitly goal-oriented, trying to figure out some specific aspect of the problem. Reasoning does not have to be correct to be coded as analysis. Exploration represents less focused behavior, where the student is searching for options or trying things out with little direction or expectation of moving forward. It is generally not clear what they expect to find through their efforts. On average, the experts spent 43% of their time on Analysis and 1% of their time on Exploration, while the novices spent 25% of their time on Analysis, and 16% of their time on Exploration. Note that the difference between Analysis and Exploration was the major focus of interrater reliability checks.

DISCUSSION AND CONCLUSION

In this paper, we presented example data describing the differences between expert and novice problem solvers when handling multiple representations. Some of our results were expected: Experts were more successful in solving problems that required the use of multiple representations, finished faster, and moved more quickly between the representations available. However, we were surprised to find that these novice problem-solvers were just as likely to use multiple representations extensively in their solutions. Novice

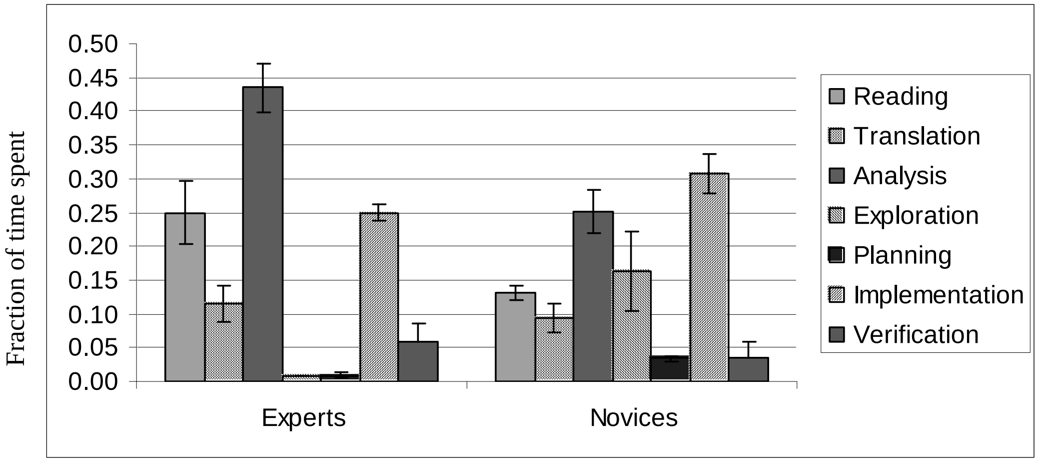


FIGURE 2. Average fraction of solution time spent in various ways by experts and novices. Error bars represent the standard error of the mean.

solutions also included on average more translations between the different representations at hand, matching our qualitative observation that students 'flailed about' when stuck, whereas the experts proceeded more systematically.

Over the course of this study, it appeared to us that considering only the number, kind, and correctness of the representations used would not fully characterize the differences between the experts and novices. In response, we have coded and analyzed the behaviors that our subjects engaged in while using these representations. The time spent in different activities was quite similar except in the categories of Analysis and Exploration. Experts spent much more of their time pursuing specific goals or sub-goals even when they did not know exactly how to proceed, as with the more challenging pulley problem not presented here. Novices still spent some time in this manner (which is encouraging), but were much more likely to engage in exploration with no clear purpose, perhaps hoping to strike a more correct approach.

The analysis presented here is preliminary, but suggests some key differences between expert and novice problem solvers. A number of studies (including refs. 5-8) have demonstrated success in getting novice physicists to use multiple representations, but usage alone is insufficient. We believe that careful characterization of how and why students use multiple representations will provide clearer paths for instruction, and suspect that attending to meta-level skill sets (like knowing what different representations are useful for) may result in more expert-like use of problem-solving time and greater success.

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