Searching For Evidence Of Student Understanding

Tara Bartiromo, James Finley, and Eugenia Etkina

Graduate School of Education, Rutgers University,
10 Seminary Place, New Brunswick, NJ 08901

Abstract. There is a strong emphasis in physics education research on the use of multiple representations to help students explain physical phenomena and to solve physics problems. In this paper, we report on students' use of multiple representations in the analysis of kinematics problems. The students learned kinematics using the Physics Union Mathematics curriculum*. When we examined pairs of representations in student work (motion diagrams and graphs), we found that students were often consistent but not necessarily correct. Based on the patterns in the data we argue that to fully assess student understanding we need to provide students with problems that require them to use at least two different representations to explain their answer. *Work supported by NSF grant DRL-0733140.

Keywords: Multiple Representations, Problem Solving, Reasoning, Assessment.
PACS: 01.40.ek; 01.40.Fk; 01.40.G-

INTRODUCTION

One of the goals of physics education is to help our students think like scientists. Scientists' reason and communicate with multiple representations. Studies in physics education research on how students reason with a particular representation help the community understand how to achieve this goal. However there is a gap in the research on how students reason using several representations while solving a single problem.

The authors address this gap by analyzing students' solutions to a difficult qualitative problem (see Fig. 1) that specifically asks students to reason with several different representations. The students involved in this study learned kinematics through the Physics Union Mathematics (PUM) curriculum, a middle school-high school curriculum, which develops the physics concepts through the Investigative Science Learning Environment (ISLE) [1]. In addition to improving student conceptual understanding and strengthening their reasoning about physical phenomena, solving problems with multiple representations is a major goal. We want students to solve problems by first drawing a picture and representing the problem situation with force and motion diagrams, energy bar charts, etc. instead of searching for the right formula.

With this work we seek to answer the following question: What do different representations provided by a student tell us about his or her understanding? In order to answer this question, we analyzed students' responses to the following problem (Fig. 1). We coded the correctness of each representation [2], noted which representations were included in the student's response and the consistency between the representations.

> Two small metal balls are dropped from the same height, but the second ball is dropped a little later than the first one. When the second ball is released, the vertical distance between the balls is 2.0 cm. Use your knowledge of how objects fall to predict what will happen to the distance between the balls as the balls fall. Explain your prediction using a motion diagram (dot diagram), a position-versus-time graph, and mathematically.

FIGURE 1. Kinematics test problem: Falling Objects

THEORETICAL FOUNDATION

Multiple representations play a significant role in expert problem solving. In addition to having a sophisticated knowledge schema [3], experts recognize the importance of solving problems by first reasoning qualitatively [3, 4, 5]. Although novices often start a problem by drawing a picture [6], experts are aware of how to use this pictorial representation to reason about the problem and to help them develop a strategy to solve the problem [4, 5, 7]. Very often, this pictorial representation leads experts to additional representations before they move on to a quantitative solution [4, 5]. Novices often are not sure how to use the picture and proceed by looking for an equation that matches the physical quantities in the problem [4].

In addition, experts are also skilled at translating fluently between representations [3, 7] and in using different representations to solve problems. Kozma & Russell determined that chemists actually do use a variety of representations when solving real-life problems in the laboratory [3].

There is a great deal of research on students' use of representations. Several studies indicate that students can and do in fact use representations to solve problems [6, 8, 9], but this is only the case when the course explicitly or implicitly emphasizes the use of multiple representations for this purpose. However, the use of a representation to solve a problem does not automatically lend itself to success [6]. The following are significant factors: the representation format in the problem statement [10, 11], the representation used by the student to solve the problem [12], and the representation quality [6, 9].

The current study builds on this body of research. It examines whether students can translate between representations (what we call consistency) and how requiring multiple representations for a single problem uncovers different aspects of students' understanding.

DESCRIPTION OF THE STUDY

High school physics students from two different districts learned kinematics through the PUM curriculum. At the end of the unit on kinematics, students took a two-part summative assessment. The first part was strictly multiple-choice questions; the second part consisted of seven open-response questions. In this study, we specifically focused on students' responses to one qualitative open-response question. The question as it appears on the assessment is shown in Figure 1. At the time of this study, 167 students had responded to the test question. The two districts are comparable in socio-economic status (middle class, suburban) and the teachers involved went through the same training. Due to the similarity of the students, we analyzed the data together.

We examined students' responses to the qualitative test question and identified several interesting trends. As a result, we created a coding scheme to investigate these trends and answer our research question.

Using the scheme we were able to (1) record which representations were used by each student, (2) code for the correctness of the prediction, (3) code for the correctness of each representation, and (4) identify which representations were consistent with each other regardless of correctness. To code for correctness of the representations, we used rubrics that were adapted from Etkina et al. [2]. A sample rubric used to code the motion diagram representation is shown in Table 1.

From the data we coded, we calculated percentage of students in each rubric category. We determined the percentage of students (out of 167) who used each representation in their response (Figure 2). For consistency percentages we included only students who used the representations (Figure 3).

FINDINGS

Table 2 shows the percentage of students who included each representation. Nearly all included a motion diagram and a graph to explain their answer. Most students made a written prediction of the outcome of the experiment. Surprisingly, more than half of the students also included a written explanation for their prediction (which was not requested). The difference between these two is that the prediction only states whether the spacing would increase, decrease, or remain the same, while the explanation provides a reason for why this occurs. Fewer than half tried to explain their prediction using an equation.

TABLE 2. Percent of Students Who Included Each Response Component.

Response Component	Percentage
Written Prediction	80.2 %
Motion Diagram	98.2 %
Position vs. Time Graph	90.4 %
Mathematical Statement	47.9 %
Written Explanation (not required)	60.5 %

To analyze the data on the correctness of each representation, we tabulated the number of students receiving each rubric score for each representation. We then combined the students who received scores 0 and 1 as separating these categories yielded no useful information. Figure 2 summarizes the percentage of students in each score category based on the response component assessed (prediction or representation). Students were moderately successful at predicting the outcome of the experiment despite the test question being a far transfer problem [13]. Interestingly, when we examine only correct responses, students actually

TABLE 1. Motion Diagram Coding Rubric.

Missing (0)	An Attempt (1)	Needs Some Improvement (2)	Acceptable (3)
No motion diagram is constructed.	Diagram does not represent motion properly, either spacing of the dots or the directions and length of the v arrows or delta v arrows does not match the motion.	Diagram has no errors but is missing one key feature: dots that represent position, or velocity arrows, or delta v arrows.	The diagram contains no errors in dots, v arrows, or delta v arrows, and it clearly describes the motion of the object.

did better at explaining using a graph than a motion diagram.

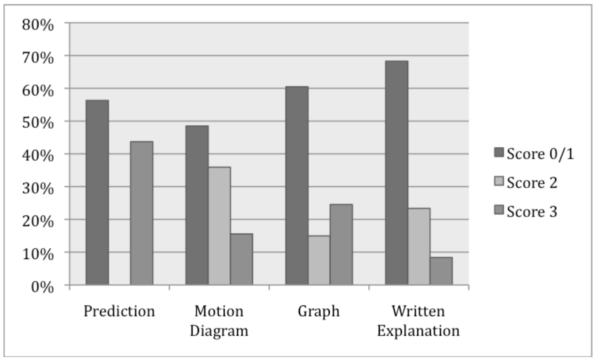


FIGURE 2. Graph illustrating the percent of students who received each score broken down by response component.

Table 3 shows how students performed on the motion diagram or graph based on how they did with their written prediction. For example, of the students who gave a correct prediction (74 students out of 167), only 22% provided a correct motion diagram. This table again shows that students were more successful at creating a correct graph compared to other representations. What is also interesting about the results is that students who made incorrect predictions could still provide a correct motion diagram or correct graph! Additionally, Table 4 illustrates how many students were correct based on the multiple representations listed. Determining how many of these students also provided a correct prediction changed the number of students minimally (11 compared to 15 for motion diagram and graph).

TABLE 3. Responses on two aspects of solution.

	Incorrect Prediction (94)	Correct Prediction (73)
Correct Motion Diagram	10.6 %	21.9 %
Incorrect Motion Diagram	89.4 %	78.1 %
Correct Graph	16.0 %	35.6 %
Incorrect Graph	84.0 %	64.4 %

TABLE 4. Number of students with correct reps. compared with both correct reps. and correct prediction.

Representation Type	Correct Representation	Correct Prediction
MD & Graph	15	11
Graph & Equation	11	5
MD & Equation	10	5
MD, Graph, Equation	3	3

We created a graph (Figure 3) to demonstrate the consistency between the different representations. The representations are listed for each bar and the number in parentheses indicates how many students were in each category (in order to calculate percentages). The dark gray bar illustrates the percentage of students who included consistent representations. The light gray bar demonstrates the percentage of students whose representations were both consistent and correct. We see that although students had consistent representations, sometimes the representations were not correct in explaining what happens to the spacing.

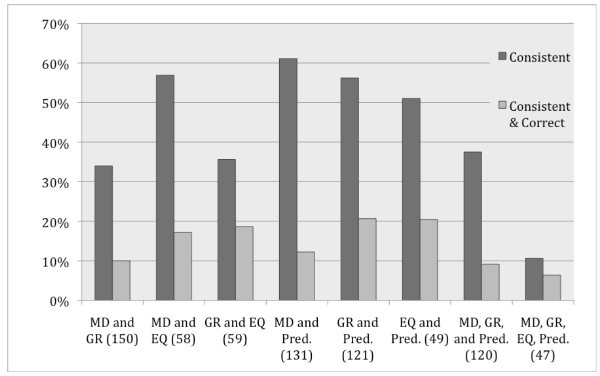


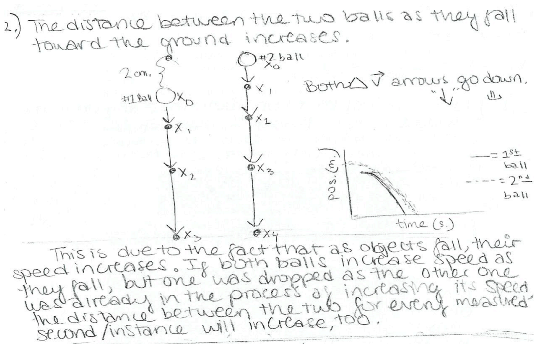
FIGURE 3. Graph illustrating percent of students who had each group of representations consistent with each other or consistent with each other and correct.

We include two examples of student's work to help illustrate our findings (Figure 4). Student 1 correctly predicts the spacing will increase and provides both a perfectly correct motion diagram and a correct explanation. The graph demonstrates that the student understands the objects are accelerating and the spacing is increasing, but is not consistent with the other representations. Student 2 incorrectly predicts the spacing stays the same and illustrates this with the motion diagram and graph. The representations and prediction are completely consistent.

DISCUSSION

Our data analysis can be summarized as follows. First, similar to prior findings, students performed differently based on the representation assessed [10, 11]. Second, students can provide consistent representations without those representations also being correct. The ability to translate fluently between representations (consistency) is an expert trait [3, 7] but appears to be insufficient to demonstrate understanding. Third, students can make a correct prediction even when there is little or no evidence of understanding in the representations they provide. Fourth, when students provide at least two correct representations, there is sufficient evidence of student understanding. Fifth, asking students to make a prediction or provide a written solution statement in addition to at least two correct representations allows us to see whether they are using the representations to reason about the solution.

Student 1



Student 2

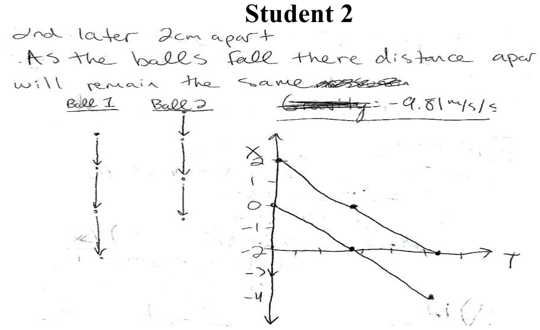


FIGURE 4. Sample student solutions.

One might argue that students perform differently depending on the representation assessed due to their representation competence. To test this explanation we correlated student performance on multiple-choice questions with the rubric score on the open response problem for each representation. Although the correlations are small (R^2_{avg}=0.15), they are statistically significant (p=0.001); student proficiency with the representations explains 15% of the variance.

From these results we can argue that by assessing students with MC questions or by requiring only one representation, one might get a false sense of students' mastery. To test this claim we correlated students' scores on the multiple-choice portion of the test with their overall score on this open-response question. The results showed a small but significant correlation (R^2=0.22; p=0.001). Those who did well on MC did not necessarily succeed on our problem.

Further investigation with more than one open-response question is necessary. However, we can still consider the implications of this study. Relying on multiple-choice assessment strategies, we miss out on measuring deep student understanding. Therefore, assessments need to include problems in which students respond with more than one representation so that the instructor gets a clear picture of the students' strengths and weaknesses. This agrees with what prior research recommends [3, 6, 12]. Requiring multiple representations will, in turn, discourage students from impulsively responding to assessment problems. In addition, we can identify the parts of the problem statement to which students pay attention and how they interpret this information. Finally, if the emphasis is placed on open-ended and multi-dimensional questions students will learn that learning and thinking is so much more than plug and chug. The fact that students include written explanations even when they are not requested is a sign that they understand this distinction.

In terms of solving problems like experts, students do not necessarily use a representation to answer a question; meaning they may have a correct motion diagram, graph, or mathematical statement but their prediction is incorrect. At the same time, we do see that students are fairly consistent; yet, this consistency does not seem to translate to a correct response. Considering a major aspect of expert problem solving is the ability to transfer between representation, there needs to be a stronger emphasis on reasoning with more than one representation, assessing the correctness of representations once they have been created, and checking for reasonableness of the solution. In this way, students will be more successful when solving problems or analyzing experimental evidence.

This study is limited in that we use a convenience sample. In addition, this is only an observational study. Future research should include a think-aloud interview protocol. However, we believe the results can be generalized to the total population, specifically with regard to assessment and instruction.

REFERENCES

1. E. Etkina and A. Van Heuvelen, "Investigative Science Learning Environment" (2006, 2001).
2. E. Etkina, et al., *Phys. Rev. Special Topics, PER* **2,** 020103 (2006).
3. R. Kozma and J. Russell, *JRST* **34**, 949-968 (1997).
4. A. Van Heuvelen, *Am. J. Phys.* **59**, 891-897 (1991).
5. D. A. Stylianou and E. A. Silver, *Math. Think. Learn.* **6,** 353-387 (2004).
6. D. Rosengrant, A. Van Heuvelen, and E. Etkina, *Phys. Rev. Special Topics, PER* **5**, 010108 (2009).
7. P. B. Kohl and N. D. Finkelstein, *Phys. Rev. Special Topics, PER* **4**, 010111 (2008).
8. C. J. De Leone and E. Gire, in *2005 Physics Education Research Conference,* edited by P. Heron et al., AIP Conference Proceedings 818, Salt Lake City, Utah, 2005, pp. 45-48.
9. P. B. Kohl, D. Rosengrant, and N. D. Finkelstein, *Phys. Rev. Special Topics, PER* **3**, 010108 (2007).
10. P. B. Kohl and N. D. Finkelstein, *Phys. Rev. Special Topics, PER* **1**, 010104 (2005).
11. D. E. Meltzer, *Am. J. Phys.* **73**, 463-478 (2005).
12. R. Dufresne, W. Gerace, and W. Leonard, *The Physics Teacher* **35**, 270-275 (1997).
13. S. M. Barnett and S. J. Ceci, *Psychological Bulletin* **128**, 612-637 (2002).