An Overview of Recent Research on Multiple Representations

David Rosengrant, Eugenia Etkina and Alan Van Heuvelen

Rutgers, The State University of New Jersey
GSE, 10 Seminary Place, New Brunswick NJ, 08904

Abstract. In this paper we focus on some of the recent findings of the physics education research community in the area of multiple representations. The overlying trend with the research is how multiple representations help students learn concepts and skills and assist them in problem solving. Two trends developed from the latter are: how students use multiple representations when solving problems and how different representational formats affect student performance in problem solving. We show how our work relates to these trends and provide the reader with an overall synopsis of the findings related to the advantages and disadvantages of multiple representations for learning physics.

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INTRODUCTION

A representation is something that symbolizes or stands for objects and or processes. Examples in physics include words, pictures, diagrams, graphs, computer simulations, mathematical equations, etc. Some representations are more concrete (for example, sketches, motion diagrams and free-body diagrams) and serve as referents for more abstract concepts like acceleration and Newton's second law—they help student understanding. Mathematical representations are needed for quantitative problem solving. More concrete representations can be used to help apply basic concepts mathematically. For example, students can learn to use free-body diagrams to construct Newton's second law in component form as an aide in problem solving. Consequently, many educators recommend the use of multiple representations (MRs) to help students learn and to solve problems [1-7].

This manuscript describes recent multiple representations studies by the physics education research community [1-17] including our own work in this field.

RECENT TRENDS

In this section we provide an outline of the recent trends in multiple representation research [2003-2005] in the PER community. These trends form a logical sequence. The sequence begins with the major question of whether using MRs helps students learn concepts and learn to better solve problems. Concerning problem solving, what instructional innovations actually help students use MRs while solving problems? And if they do use them, then how do they use them to help solve the problem?

A separate line of research relates to problem posing – how does the representation in which the problem is posed affect student performance and their decision to use another type of representation when solving the problem?

Table 1 compiles the studies used for this paper into an easy reference for those who wish to read the full articles. The numbers in the table correspond to the references in the manuscript.

TABLE 1. References to multiple representation studies.

Research Trend			
MRs help students learn concepts and solve problems		6, 7	
	Do students use them?	**Do they help students**	**What MRs do students choose?**
Use of MR to solve a problem	5,8,11,12	5,8,11,12	12,13
Use of MR to pose a problem		13,14,15,16, 17	13

Next, we describe the details of the different trends.

Multiple Representations Help Students Learn Concepts and Solve Problems

Hinrichs [6] describes how using a system schema (object of interest is circled, objects that are interacting with it are circled and then connected to it via labeled arrows) helped his students learn dynamics. He used the system schema as part of a sequence of representations (problem text, sketch, system schema, free body diagram, and finally equations) to solve a problem. He compared classes where he used system schemas with classes where he did not use schemas. The 28 students who learned to use system schemas increased from 1.1 ± 1.0 questions out of 4 questions correct on Newton third law FCI pretest questions to 3.7 ± 0.8 on the post-test. The 31 students who did not learn to use a system schema scored a 1.2 ± 1.0 on the same 4 questions on the pre-test and 2.8 ± 1.2 on the post-test. The author reports that the system schema had a significant effect on student learning.

Finkelstein et al. [7] used computer simulations to aide students in learning DC circuits. The simulations provide visual representations of concepts such as current flow and Kirchoff's laws. They found that students who learned concepts related to DC circuits via computer simulations and never built a real circuit performed significantly better on 3 exam questions that related to DC circuits than students who learned using real circuits. They also found that the former students could build and explain real circuits faster (14 minutes compared to 17.7). The authors report that this is a significant difference. There was no significant difference on non-circuit questions. The visual simulation representations had a significant effect on understanding and problem solving.

Use of Multiple Representations and Problem Solving

Several studies investigated whether the use of multiple representations in courses affected student problem solving. De Leone and Gire [8] studied how many representations students in a reformed course used when solving open-ended problems on quizzes and tests. They analyzed student's work on 5 problems and found that 31 of 37 students used 4 or more representations total (they called them high MR users).

Our group [5,11,12] investigated students' use of one representation – a free body diagram (FBD) – when solving multiple choice problems in mechanics and static electricity. The experimental group used the *ISLE* curriculum in which multiple representations are central to students' learning [9]. We found that on average 58% of the students drew an FBD while solving a multiple choice problem even though they knew that no credit was given for the diagrams. Only 15% of students in traditional settings use FBDs to help them solve problems [10].

The research by Rosengrant, Etkina and Van Heuvelen and by DeLeone and Gire shows that if students learn physics in an environment that emphasized the use of multiple representations, students will use them to help solve problems. Does the use of these different representations improve problem-solving performance?

DeLeone and Gire [8] found that those students who successfully solved 3 or more of the 5 coded problems were all high MR users. They drew a picture, an extended force diagram, an energy system diagram, or plotted a graph. On 4 out of those 5 problems students who used representation other than mathematical had a higher success rate than those who did not. De Leone and Gire did not assess the quality of the representations that student constructed.

We investigated a similar question, but took our analysis one step further [5,11]. We related student success on a problem with not only the presence, but the quality of the representation—in our case a free body diagram. Table 2 contains the average results from our two year study of 245 students answering several multiple-choice problems in different conceptual areas. The first column states the quality of the free body diagram assessed by a specially designed rubric on a scale of 0-3. The second column shows the number of students who correctly solved a problem with that quality of FBD divided by the total number of students who drew an FBD of the same quality. The last column is the percentage of the previous column. The average percentage of correct answers for all problems was 60% (a measure of the difficulty of the problems). The results suggest that FBDs are most beneficial to students if they are constructed correctly. If a student constructs an incorrect free body diagram, then they actually have a lower chance to correctly solve the problem then if they had no free-body diagram.

TABLE 2. Average of Two Year Study [11].

Quality of FBD	Number of students with correct answer divided by total number with same quality diagram	%
Correct (3)	251/295	85
Needs improvement (2)	261/370	71
Inadequate (1)	69/181	38
None (0)	304/619	49

In the PERC 2005 proceedings paper we reported on a qualitative study (6 students) [12] using think aloud interviews that investigated what representations students chose to help them solve problems involving forces and why they constructed the representations. We found that all students, even those who could not solve the problem, drew a picture for the problem situation but only those who were in the reformed *ISLE* course constructed free body diagrams to help them solve the problem. The high achieving students in the sample used the representations not only to help them solve the problem but also to evaluate their work.

In new and unpublished work, we have also found that the way the problem is posed can affect whether students will use an FBD to solve it. We used several multiple-choice exams with 245 students where a total of 12 problems that involved forces (mechanics or electrostatics) were selected for the study. On the exam sheets, many students drew FBDs for some problems and few for others. Was there any pattern in their choices? To answer this question we grouped these 12 problems into three categories based on the number of students who constructed an FBD to help them solve that problem [Table 3]. We placed a problem in a 'Low' category if fewer than 50% of the students constructed an FBD to solve it; in a 'Medium' if between 50 and 60% constructed an FBD; and in the 'High' category if more then 60% constructed an FBD.

Though all of the problems were multiple-choice in design, there were features that were different across the problems. Some problems had a picture in the text and some did not. Some were more difficult than others. Some problems asked students directly to determine a force and some did not. Finally, some problems were in mechanics and some in electrostatics. How did these differences contribute to students' decisions to draw an FBD? Table 3 shows the relationship between these factors and the questions in each group.

TABLE 3. Possible relationships between type of problem and how likely students are to construct a diagram for it.

Factors	Low	Medium	High
# of problems	4	3	5
Picture present	2 with 2 w/o	2 with 1 w/o	0 with 5 w/o
Average Success Rate	52.75%	65.7%	63.8%
Problem asks for a Force	2 No 2 Yes	1 No 2 Yes	0 No 5 Yes
Type of Problem	2 Mech. 2 Elect.	1 Mech. 2 Elect.	4 Mech. 1 Elect.

We correlated our results from Table 3 and found that the highest correlation between the percentage of students who constructed an FBD and an influencing factor was if the problem asked for a force [Pearson correlation coefficient 0.502]. The next highest correlation was if a picture was present [correlation coefficient -0.479]. The negative correlation implies that if a picture is present, a student was less likely to construct an FBD. The difficulty of the problem and whether the problem was in mechanics or electrostatics did not have a big effect on student choices [correlations of 0.395 and 0.278]. None of the correlations was statistically significant though the top two factors were close to being significant. This is not surprising since the sample size for the number of problems in the study was very small [N=12].

This result suggests that when the instructor supplements the text of the problem with the picture, the students are less likely to construct a free body diagram to solve the problem. One explanation can be because the provided picture helps the students understand the problem situation and thus they think that they do not need to draw an FBD. Also, if the problem asks students to solve for a force, they are more likely to construct an FBD to help them solve that problem. One possible explanation for this is that the word force in the problem statement triggers a "FBD schema." Problems involving similar concepts but asking for acceleration do not trigger this schema. However, there needs to be more research in this area before we can verify these trends.

Use of Multiple Representation to Pose A Problem

This area of research investigates the relationship between student success and the representational format in which a problem is posed. The first question relates to student choices of the problem format: if they are given this choice, what will they choose? Kohl and Finkelstein [13] found that more students prefer the problem statement to be represented with a picture than with words, graphs or mathematical equations. However, this does not necessarily make them more successful in solving the problem.

For example, on a question in wave optics students who chose a pictorial format did significantly better then the control group. However in atomic physics the students who chose a pictorial format did significantly worse then students in the control group. There was no clear pattern what format made the problem more difficult. However, in their second study [16,17] they found that students who learned physics with the instructor who used lots of representations were less affected by the representational format of the problem. Therefore if we want our students to be able to reason flexibly, it appears that the use of multiple representations when they are learning new material helps.

Dancy and Biechner [14] used computer animations for some questions on the pre-test FCI in an experimental group and traditional questions in a control group. They found significant differences on 6 of the questions between the two groups. On 3 questions, the animations group performed significantly better, while on 3 other questions the control grouped performed better. After conducting interviews they found that for the problems including motion, the animations clarified the problem statement and helped students make answer choices more consistent with their understanding (and not necessarily correct). They concluded that a simulation format is especially beneficial for those students who have reading comprehension problems. Animations in the problem statement lead to a more accurate assessment of student reasoning because students have a better understanding of the intent of the questions.

Meltzer's study [15] compared students' responses to a variety of isomorphic physics problems posed in different ways: in words, with a vector diagram, with a circuit diagram, etc. He found that "student performance of very similar problems posed in different representations might yield strikingly different results" (p. 473). The same student can answer a Newton's third law question posed in words correctly and choose an incorrect answer to the very same question posed with a picture with vectors. He also found that females were particularly harmed by the non-verbal representations of the problem statements.

DISCUSSION

The general consensus of the described work is that representations are important for student learning. They assist students in acquisition of knowledge and in problem solving. We can say that using high quality multiple representations while solving a problem is a sufficient condition for success but it is not a necessary condition. Students use representations to help them understand the problem situation and to evaluate the results. Representations in problem statements can have different effects on student performance and on their choice to use other representations. For some problems a computer animation can clarify the situation for the students and help them display their real reasoning. Students who learn the material in an environment that uses more representations are less affected by the representational format of the problem statement. Another finding is that certain words in the problem statement may trigger the use of particular representations, though more research must be done to verify this finding.

There has been a recent growth of research in multiple representations. This growth is expanding rapidly with many opportunities for future researchers. They can: focus on what factors influence students to construct representations, replicate studies with other representations or investigate the quality of representations students construct.

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