# Student Representational Competence and the Role of Instructional Environment in Introductory Physics

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**Abstract.** In a previous study of a traditional, large-lecture algebra-based physics course, we demonstrated that giving students a choice of representational format when they solve quiz problems could have either significantly positive or negative performance effects, depending on the topic and representation used. Further, we see that students are not necessarily aware of the representation with which they are most competent.[1,2] Here, we extend these results by considering two courses taught by a reform-style instructor. These performance data are substantially different in character, with the students from the reform courses showing much smaller performance variations when given a choice of representation. From these data, we hypothesize that students in the reform courses may be learning a broader set of representational skills than students in the traditional course. We therefore examine major components of the courses (exams, homeworks, lectures) to characterize the use of different representations. We find that the reform courses make use of richer selections of representations, and make more frequent use of multiple representations, suggesting a mechanism by which these students could have learned these broader skills.

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## INTRODUCTION

Our previous work[1,2] showed that physics students' success with physics problems depends strongly on the representation of the problem, corroborating other work in PER.[3] That is, whether a physics problem is represented in terms of words, equations, graphs, or pictures can have a significant impact on student performance on that problem. We also investigated whether providing students with a choice of representational format would help or harm their problem solving performance; that is, can students determine which representations are most helpful to them on problems from a given topic? This is a meta-representational question, in that we ask what students know *about* representations.[4] The results from our study were complicated: Students' problem solving performance often depended strongly on whether or not they had a choice of format, but the strength and direction of the effect varied strongly with the representation and the subject matter.

Our last study involved a large-lecture, algebra-based Physics 202 course taught by a mostly traditional professor. There, we primarily considered the effect of micro-level features of the problem context (specifics of the topic and the representation) on student representational competence. In this study, we consider the effect of more macro-level features. In particular, we wish to see the impact of changing either the subject area or the instructional style. We thus repeat the earlier study in a 202 course taught by a reform-style professor and in a 201 course taught by this professor. In the reformed courses we find the data are much different in character than in the traditional 202 course, with the possible interpretation that the students in the reformed course environment are learning a broader set of representational skills. We then analyze the representational content of the reform and traditional 202 courses and find that the reformed course is indeed richer in terms of representations, including the use of multiple representations. A more detailed description of the methods and data will be available in a forthcoming long-format paper.[5]

## REPLICATION - METHODS

In this study, as in the previous, we gave students pre-recitation homeworks that had four problems, one in each of four different representational formats (verbal, mathematical, graphical, and pictorial).* We

* We do not mean to imply that this categorization of representations is unique or complete. Further, any particular problem or concept does not necessarily fit exactly in any one representational category.

**TABLE 1. Statistical significances of the performance differences between format choice and random assignment (control) groups, organized by class, topic, and quiz representation. X indicates p > 0.10. Bold indicates that the choice group outperformed the control group. Numbers in parenthesis show the total number of students in the indicated group.**

| | **Diffraction** | | | | **Spectroscopy** | | | |
|---|---|---|---|---|---|---|---|---|
| | Verbal | Math | Graph. | Pict. | Verbal | Math | Graph. | Pict. |
| **Phys 202** (Trad) | **X** (N=34) | X (N=75) | 0.04 (N=42) | **0.03** (N=78) | **0.002** (N=40) | **0.0001** (N=57) | **0.0004** (N=44) | 0.001 (N=76) |
| **Phys 202** (Reform) | **X** (N=62) | 0.06 (N=80) | **X** (N=83) | X (N=121) | X (N=63) | X (N=71) | X (N=79) | X (N=135) |
| | **Springs** | | | | **Pendulums** | | | |
| **Phys 201** (Reform) | X (N=54) | **0.09** (N=141) | **X** (N=59) | **0.07** (N=79) | **X** (N=63) | **X** (N=68) | **X** (N=79) | **X** (N=123) |

then gave these students a one-question quiz during their recitation section. This quiz was in one of four formats, and one-half of the sections were allowed to choose which quiz format they would receive without examining the questions ahead of time. The rest of the sections received a quiz in a random format, serving as a control group. This process was repeated later in each term for a different topic, providing a total of four trials. The 201 quiz topics were springs and pendulums, while the 202 quiz topics were diffraction and spectroscopy. All homework problems and quizzes are available in a long-format paper.[2]

## REPLICATION - DATA

In the previous study, we examined both homework and quiz performance data, in part to investigate how student performance varied across representation. In this paper, we focus on the differences between students who received a choice of quiz representation and those who did not, and on how those differences were influenced by the course environment. Thus, we restrict our attention to the quiz data, shown in Table I. In the table we document whether students selecting a quiz format outperformed their counterparts who were assigned a random format quiz. We show the statistical significances of the differences in performance between the two groups and include data from Ref. 1.

One can compare the performances of the choice and control groups for any particular topic and representation. In the traditional 202 course of the first paper, there were eight possible choice/control comparisons. We observed six statistically significant splits, where either the choice or control group did significantly better than the other.[1] In the reformed 201 and 202 courses, none of the 16 choice/control splits are statistically significant at the $p = 0.05$ level, and only three are significant at the $p = 0.10$ level. This is a striking difference in character, especially since the 202 courses used identical quiz materials.

Since both the reform 201 and 202 choice/control data sets were significantly different from the traditional 202 data set, we hypothesized that students in the reform environment were learning a broader set of representational skills. If this were the case, there would likely be less difference between student performance on a selected representation and student performance on an assigned representation, and would explain the presence or absence of choice/control splits. To explore where students might be developing such skills, we analyzed the three courses to determine whether the reform courses were richer in representational content.

## ENVIRONMENTS - METHODS

The second part of this study involved characterizing the representation use in each of the classes under consideration: the reform 201, the traditional 202, and the reform 202. These courses had many components, including lecture, lab/recitation, exams, and homeworks. The homeworks included problems assigned and graded through a web-based automated system (CAPA)[6] and long-answer hand-graded problems. In comparing the courses, we judged the labs/recitations and CAPA-based homeworks to have similar selections of representations. The lectures, exams, and long-answer homeworks show more substantial differences. Analyzing these components provides two views of the class. We see how the use of physics representations was modeled for students (lectures), and how students were held responsible for using physics representations themselves (homeworks and exams). To conserve space, we restrict ourselves to an analysis of the exams. Results for the remaining components are similar qualitatively, and will be available in a long-format paper.[5]

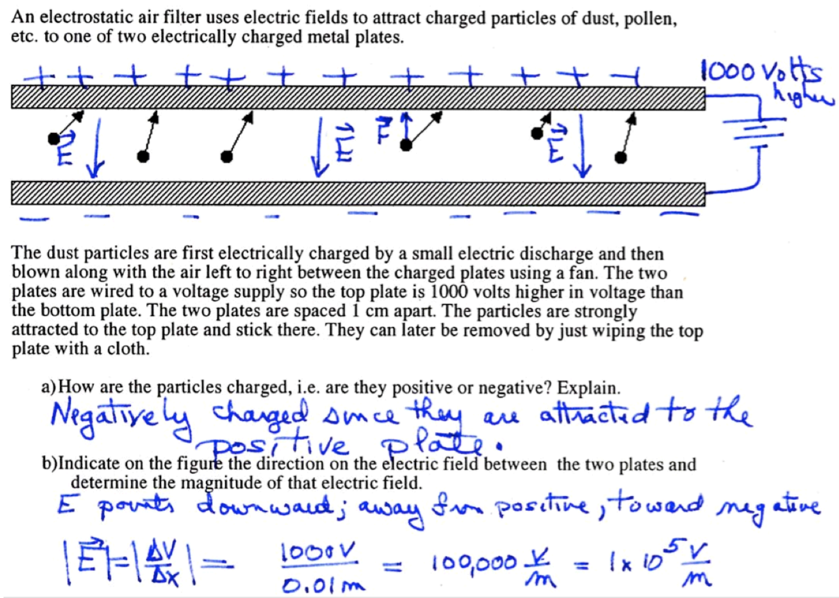


**FIGURE 1.** Example exam problem and instructor solution with pictorial, mathematical, and verbal components. The problem is from the reform 202 course.

Each of the courses had three exams, not including the final (which took place after the study quizzes). We quantified the portion of each of these exams that could be described as verbal, mathematical, graphical, and pictorial in representation. We also quantified the fraction of each exam that explicitly required the use of multiple representations. A more detailed description of the methods along with the standards for each representational category are available in the long-format paper. For now, we note that problems with more than one representational component had their points counted in full towards each of the relevant representations; no effort was made to weight the components. Thus, an exam that was rich in representations could have more than 100 points of representational content assigned to it in this analysis. Figure 1 shows an example exam problem from the reformed 202 course with verbal, mathematical and pictorial components. Any problem that explicitly involved more than one representation had its points counted towards a Multiple Representations category as well. Once we characterized each exam in terms of its representational content, we calculated the average representational content of the exams in each course.

## ENVIRONMENTS – DATA

In Figure 2, we show the representational content of the exams in the reformed Physics 201, reformed 202, and traditional 202 courses. These data show the average across all exams in each course, excluding the final exam. We see the fraction of the exam problems (weighted according to their point value) that were verbal, mathematical, graphical, and pictorial in nature. We also see the fraction of the exam problems that required explicit use of multiple representations. It is clear that the exams from the reform sections of 201 and 202 made use of a broader selection of representations than did the traditional 202 section. Perhaps most striking is the difference in the proportion of multiple-representation problems, with 52% of the reform 201 and 74% of the reform 202 exam problems making use of multiple representations, and 26% of the traditional exam problems doing so. The difference between the reform 202 and traditional 202 figures is statistically significant ($p < 0.0001$, two-tailed binomial proportion test), as is the difference between the reform 201 and traditional 202 ($p = 0.03$).

## DISCUSSION AND CONCLUSION

With the data shown here, we can see how choice vs. control group performance varies across both topic area and instructional environment. Providing identical quiz materials to two differently taught 202 courses allows us to conclude that presence or absence of the choice/control splits is influenced primarily by the instructional style, broadly conceived. Also, analysis of the course data demonstrates that major components of the class were strikingly different in their representational character with the reform content being richer and using multiple representations more frequently.[*]

[*] Note that these data address only the quantity and not the quality of representation use. While we consider the reform course to have been more successful in both regards, presently we consider only the quantity of representations.

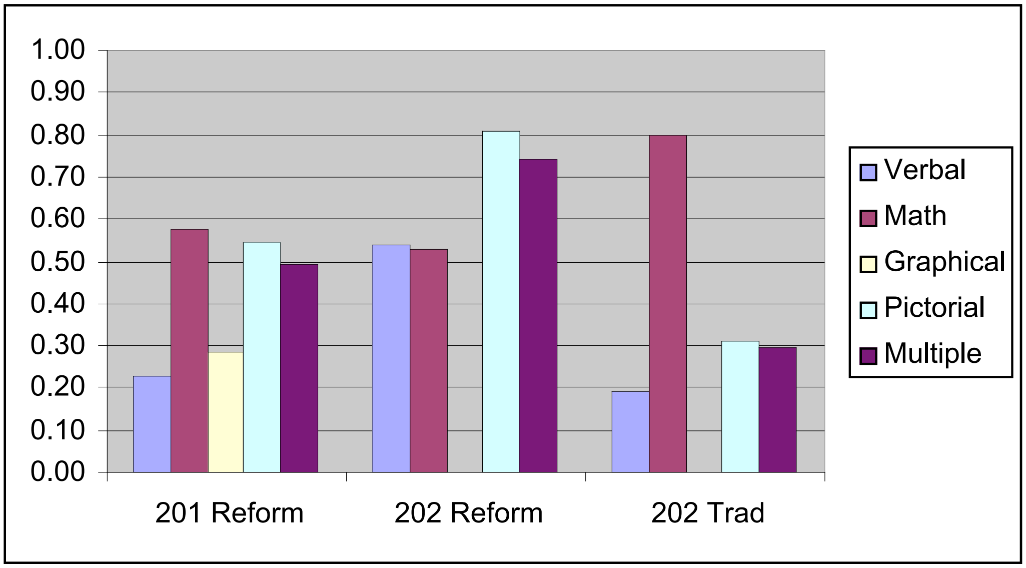


**FIGURE 2.** Distribution of representations used and fraction of exam requiring explicit use of multiple representations in the three courses studied.

This richer use of representations in class is consistent with the notion that these students are learning a broader set of representational skills, which would explain the choice/control splits or lack thereof. With this broader set of skills, working in a chosen representation as opposed to an assigned one could have less impact on performance. It is also perhaps significant that the reform 202 section shows generally smaller performance variations across representation within the choice and control groups (not shown).

While the students in the reform sections appear to be more consistent in their skills across representation, we caution against concluding that these students have developed greater meta-representational skills. It is quite conceivable that these students were no better than the traditional 202 course at assessing their own abilities and evaluating the different representations available to them, and that their broader set of representational skills made any meta-representational failures less significant. Of course, neither do the data allow us to conclude that the reform 202 students were *not* learning better meta-representational skills.

Our results suggest that instructional environment can play a significant role in developing student representational skills as they apply to physics problems. Pervasive use of different representations and of multiple representations appears to have broadened students' representational skills, as indicated by the disappearance of the choice vs. control splits. Unfortunately, without assessment tasks that are less sensitive to the topic coverage, we are limited in our ability to conclude that student representational skills are stronger in a reform-style class in an absolute sense; all we are comfortable in asserting is that student problem solving skills varied significantly less from representation to representation. Nevertheless, we consider it plausible that as these students develop broader skills, they also develop stronger skills overall.

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