Improved Student Performance In Electricity And Magnetism Following Prior MAPS Instruction In Mechanics

Saif Rayyan, Andrew Pawl, Analia Barrantes, Raluca Teodorescu and David E. Pritchard

Physics Department and Research Lab of Electronics, MIT, Cambridge, MA 02139

Abstract. We examine the performance of a group of students in Introductory Electricity and Magnetism following a ReView course in Introductory Mechanics focusing on problem solving employing the Modeling Applied to Problem Solving (MAPS) pedagogy[1]. The group consists of students who received a D in the fall Mechanics course (8.01) and were given the chance to attend the ReView course and take a final retest. Improvement to a passing grade was qualification for the Electricity and Magnetism course (8.02) in the spring. The ReView course was conducted twice - during January 2009 and January 2010. As a control, we took a group of students with similar z-scores in 8.01 in Fall 2007 that were not offered the ReView course. We show that the ReView students perform ~0.7 standard deviations better than the control group (p~0.002) and ~ 0.5 standard deviations better than what is expected based on their performance in 8.01(p ~0.001).

INTRODUCTION

Studies show that students' prior misconceptions in Mechanics influence their conceptions in Electricity and Magnetism [1]. Students carry the same mental models they learn in Mechanics into Electricity and Magnetism [2]. In this paper, we investigate whether the gain in attitudes and problem solving skills in a reformed ReView Mechanics course [3] has any impact on performance in Electricity and Magnetism.

We examine the performance of a group of students in introductory Electricity and Magnetism following a short ReView course in Mechanics. The ReView is designed to teach students expert problem solving skills based on the Modeling Applied to Problem Solving pedagogy. Students showed significant improvement in attitudes and problem solving skills during the ReView. We investigate if this improvement transfers to their performance in the following Electricity and Magnetism course.

MAPS: PEDAGOGY TO TEACH PROBLEM SOLVING

Modeling Applied to Problem Solving (MAPS) is a pedagogy developed by the MIT RELATE group to move students toward an expert-like problem solving approach by emphasizing strategic knowledge in introductory Mechanics. In MAPS, students learn how to organize their core physics knowledge utilizing a hierarchy of models summarizing the Mechanics curriculum. Simultaneously, students learn how to approach problems by examining the system and relevant interactions. This analysis then suggests which core model(s) apply to that problem.

We implemented this pedagogy in a 3-week "ReView" course offered in the period between the Fall and the Spring semesters in January 2009 (30 students) and January 2010 (42 students). The ReView was open to students who were given a D in the Introductory Mechanics Fall course (MIT course number 8.01) and were not eligible to continue to Introductory Electricity and magnetism (MIT course number 8.02). At the end of the ReView, students were given a chance to take a retest composed of calibrated MIT final exam problems. Significant improvement on the exam was required to allow students to register for 8.02 in the spring. The class average on the final retest improved by a full standard deviation from their average in the fall course, and only 4 out of 72 students did not pass ths second final exam. We also conducted the Colorado Attitudes towards Science Survey (C-LASS) [4]. The survey

showed a significant improvement in problem solving skills and in attitudes towards physics.

In this work, we follow the ReView students who enrolled in 8.02 right after the ReView. We evaluate their 8.02 performance in two ways: relative to a baseline of 8.02 vs. 8.01 performance, and relative to a control group of students from Fall 2007 that had similar scores on the exams in 8.01 but were allowed to take 8.02 without taking the ReView.

STUDY SAMPLE

We collected data on students' performance on examinations in the introductory physics sequence at MIT over six semesters from Fall 2007 to Spring 2010. We followed the performance of all students who took 8.01 in the Fall and continued to 8.02 the following Spring without taking a break between the two courses. Scores are expressed in standard deviations from the mean of any specific course (z-scores). Using z-scores enables us to compare the performance of students from different years. We divide the students in 3 groups as follows:

Control Group

The Control Group is a group of students that passed 8.01 in Fall 2007 (N=18) with a sum of exams z-score falling between -1.2 and -1.5. The students were allowed to continue to 8.02 without any further requirements. In Fall 2008 and Fall 2009, students with similar scores in 8.01were given a D, and could only register for 8.02 after successfully passing the ReView. We use this group as a control since their 8.01 scores are similar to a group of students who took the ReView.

The ReView Students

Students who scored a D in 8.01 in Fall 2008 and Fall 2009 could not register for 8.02 without taking and passing the ReView. The ReView students had 8.01 z-scores falling between -1.2 and -1. We only examine the students who took 8.02 immediately after passing the ReView and we split them into two subgroups:
1) **ReView group 1** (N=34), with 8.01 scores ranging from -1.2 to -1.5 standard deviations, identical to the Control Group scores.
2) **ReView group 2** (N=15), with 8.01 scores below -1.5 standard deviations.

Baseline group

The Baseline Group contains the majority of students who passed 8.01 in the Fall with a sum of exams score greater than -1.2 standard deviations and continued to 8.02 in the Spring. We use the sum of exams mainly because it is the criterion to determine the passing line in 8.01. We have data for 3 years: Fall2007-Spring2008 (N=448), Fall2008-Spring2009 (N=410) and Fall2009-Spring2010 (N=440). The regression line of this group's performance in 8.02 with performance in 8.01 is used as a baseline for evaluation of the performance of the ReView students and the Control Group.

ANALYSIS

Baseline Group and Universal Fit

We fit sum of exam score in 8.02 against sum of exam score in 8.01. Figure 1 shows the distribution and the fit for Fall2008-Spring2009. The fits are consistent for the 3 years. Equations for the fit lines along with R^2 values are in Table 1.

As one might expect, there is a very strong correlation between scores in the courses. In Figure 3, we combine the 3 years and bin the students in increments of 0.3 standard deviations in terms of their 8.01 score. Figure 3 shows that the linear fit is a good representation of the relationship between scores in the two introductory courses. We extrapolate the fit to form a baseline to predict the performance of the ReView and the Control groups and to compare that to their actual averages. This procedure essentially compares students with their class cohort and cancels out effects of varying instruction or differences in grading over the different years.

TABLE 1. Equations for the regressions for different years. y is 8.02 score in standard deviations from the mean (z-score) and x is 8.01 z-score.

year	Fit Curve for the Baseline Group	R^2
Fall08-Spring09	y = 0.80x - 0.03 (N=410)	0.50
Fall09-Spring10	y = 0.74x + 0.03 (N=440)	0.41
Fall07-Spring08	y = 0.83x - 0.07 (N=448)	0.51
All years	y = 0.79x - 0.02 (N=1298)	0.47
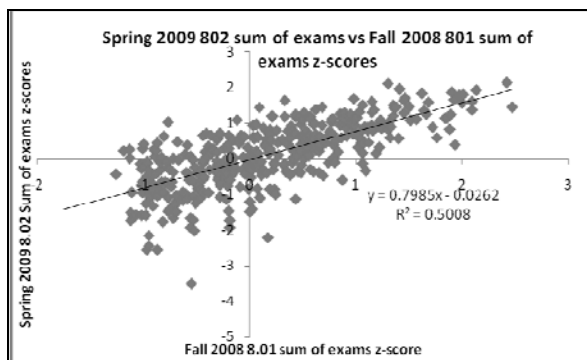
FIGURE 1. Baseline Group sum of exams in standard deviations from the mean (z-scores) in Spring 2009 8.02 vs. sum of exams z-scores in Fall 2008 8.01 (N=410). The distribution for the other two years is quite similar. The fits along with the R^2 values are given in Table 1

Control Group Compared to Baseline

The Control Group's Fall 8.01 z-score average was -1.35±0.02. The expected mean z-score in 8.02 extrapolated from the fit is -1.09±0.04. The actual mean for the group in 8.02 is -1.33±0.18, about one error bar below, but consistent with, the baseline.

ReView Students Compared to Baseline and Control Group

We first consider the ReView group 1 (the higher group) whose average 8.01 score was -1.31±0.01 standard deviation from the mean, which is comparable to the Control Group. Extrapolating the baseline fit, ReView Group 1's expected 8.02 z-score is -1.06±.04. Their average z-score in 8.02 is -0.57±0.16, significantly above the expectation from the baseline fit (p=0.002). Based on the baseline fit, ReView Group 1 performed as well as students with average 8.01 score that is 0.6 standard deviations above the ReView Group 1 average 8.01 score.

An alternative analysis is simply to compare the performance of ReView Group 1 with the Control Group whose 8.01 z-score was -1.35±0.02. This procedure is justified by the fact that the baseline fits for the three years are equal within error. ReView Group 1 performed significantly better than the Control Group; their average z-score is 0.76±0.24 above the average z-score of the Control Group (p~0.001).

Turning now to ReView group 2 (the lower group), their 8.01 scores averaged at -1.59±0.02. Their average z-score in 8.02 is -1.09±0.23 vs. a baseline projection of -1.28± 0.04. This is not a significant improvement for group 2, in contrast with results for group 1.
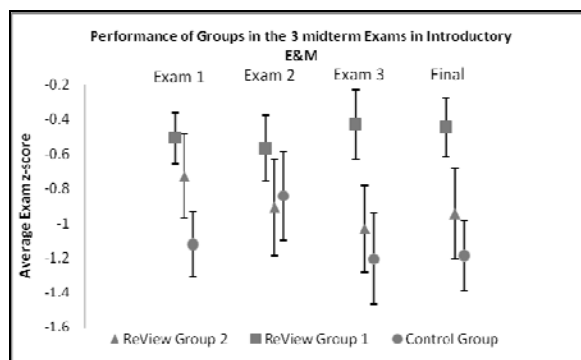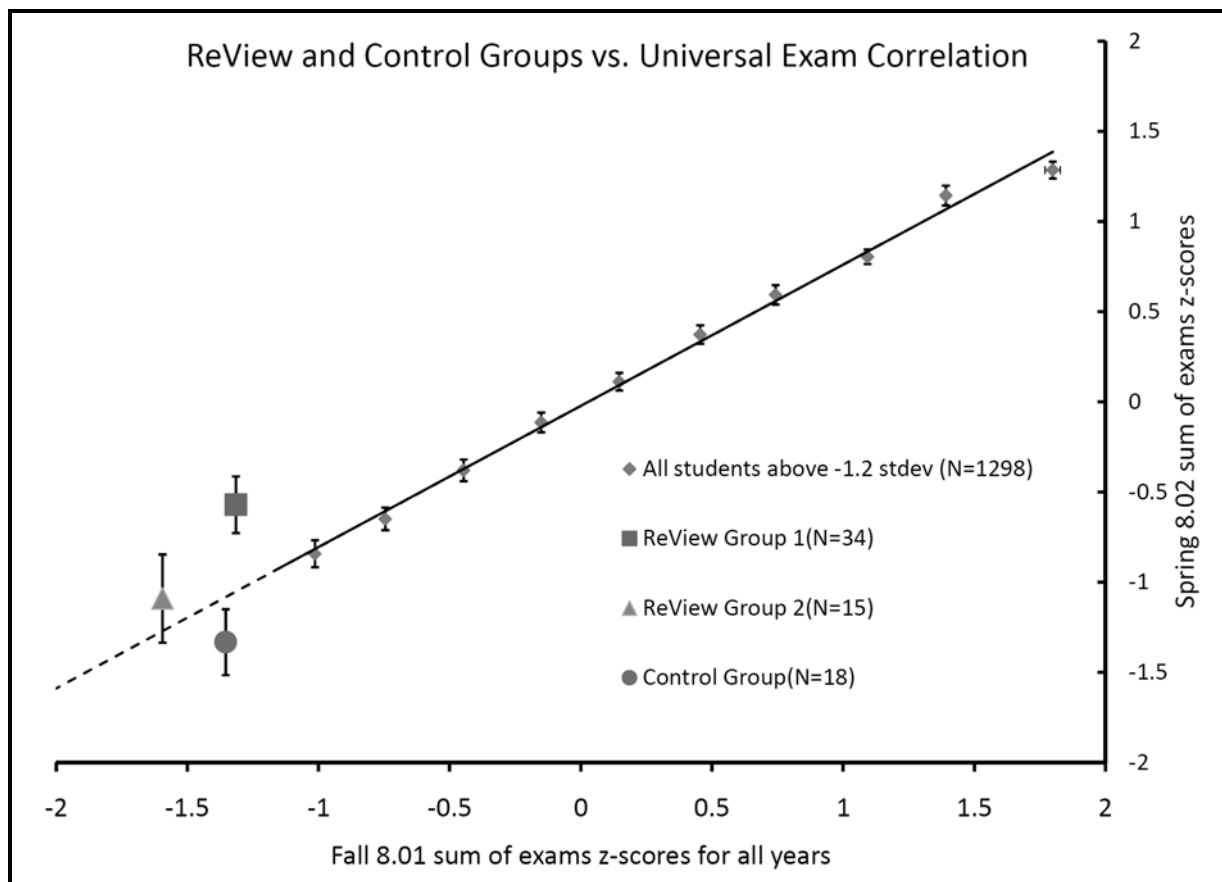

FIGURE 2. ReView and Control Groups performance on individual exams in 8.02. Group 1 performance is significantly better than the Control Group.

We also looked at the individual exam performance in 8.02 for the ReView and the Control groups, shown in Figure 2. The performance of ReView Group 1 is consistently and significantly better on all exams, and if anything slightly improves over the term. ReView Group 2's performance is slightly better (but not significantly) than the Control Group, even though the ReView Group 2 had an average 8.01 score of 0.3 standard deviations lower than the Control Group.

Table 2. Average performance in 8.02 of all of the groups compared to the expected performance from the fit. The p value indicates the significance of the difference between the extrapolated fit and the actual average

year	ReViw Group 1 (Fall z= -1.31±0.01)			Control Group (Fall z= -1.35±0.02)			ReView Group 2 (Fall z= -1.59±0.02)		
	Extrapola-ted fit	Actual	P value (1tail)	Extrapola-ted fit	Actual	P value (1tail)	Extrapola-ted fit	Actual	P value (1tail)
Fall08-Spring09	-1.08±0.06	-0.56±0.27 (N=16)	0.027	x	x	x	-1.28±0.07	-1.42±0.61 (N=5)	0.40
Fall09-Spring10	-0.94±0.06	-0.57±0.19 (N=18)	0.032	x	x	x	-1.16±0.07	-0.92±0.25 (N=10)	0.18
Fall07-Spring08	x	x	x	-1.2 ±0.05	-1.33±0.18 (N=18)	0.24	x	x	x
All years	-1.06±.04	-0.57±0.16 (N=34)	**0.002**	-1.09±0.04	-1.33±0.18 (N=18)	0.10	-1.28± 0.04	-1.09±0.24 (N=15)	0.22

FIGURE 3. Baseline students' scores binned and fitted. The 3 other points represent the averages of ReView Group 1, ReView Group 2 and the Control Group. For ReView group 1, their performance is 0.5 above the extrapolated fit (p=0.002). The control group performance and ReView group 2 performance is not significantly different from the fit.

CONCLUSION

We show that following a ReView course using MAPS pedagogy to improve problem solving ability, a group of students show improvement on their performance in the subsequent introductory Electricity and Magnetism. Students with original Mechanics scores above a cutoff of -1.5 standard deviations perform significantly better than both the Control Group and the extrapolated baseline fit of the rest of students, strongly suggesting that the improvement is a result of the ReView course. ReView students below the cutoff did not show significant overall improvement over the baseline fit, but they performed slightly (but not significantly) better than the Control Group, despite the fact that they went into Electricity and Magnetism with a lower Mechanics score average.

ACKNOWLEDGMENTS

REFERENCES

1. D. P. Maloney, T. L. O'Kuma, C. J. Hieggelke and A. Van Heuvelen, "Surveying students' conceptual knowledge of electricity and magnetism" in *American Journal of Physics*, **69**(7), 12–23, 2001.
2. S. F. Itza-Ortiz, S. Rebello, and D. A. Zollman, "Students' Models of Newton's Second Law in Mechanics and Electromagnetism." in *European Journal of Physics*, **25** (2004), 81-89.
3. A. E. Pawl, A. Barrantes and D. E. Pritchard, "Modeling applied to problem solving" in *Proceedings of the 2009 Physics Education Research Conference*, Ann Arbor, MI, 2009.
4. W. K. Adams, K. K. Perkins, N. S. Podolefsky, M. Dubson, N. D. Finkelstein and C. E. Wieman, "New instrument for measuring student beliefs about physics and learning physics: The Colorado Learning Attitudes about Science Survey," in *Phys. Rev. ST-PER,* **2**, 010101, 2006.