Retaining Students in Science, Technology, Engineering, and Mathematics (STEM) Majors

By Jessica Watkins and Eric Mazur

In this paper we present results relating undergraduate student retention in science, technology, engineering, and mathematics (STEM) majors to the use of Peer Instruction (PI) in an introductory physics course at a highly selective research institution. We compare the percentages of students who switch out of a STEM major after taking a physics course taught using traditional lectures only or one taught using PI, finding that nearly twice the percentage of students switch after the lecture-based course. By examining these results in light of the literature on STEM retention, we propose that providing opportunities for students to think, respond, and interact in class may have a substantial impact on the retention of students in STEM disciplines.

The Higher Education Research Institute recently reported finding that the proportion of incoming college students interested in science, technology, and engineering majors is rising (Higher Education Research Institute, 2010). However, although more students are considering these majors, the fraction of these students who graduate within 5 years with a science or engineering bachelor's degree is declining (Higher Education Research Institute, 2010). These findings point to the growing success of elementary and secondary education in getting more students interested in science but also suggest that more work needs to be done at the postsecondary level to help retain them. To address this need, we present results suggesting that changing to an interactive teaching pedagogy in a single introductory science course can help retain students in STEM majors.

Background

In their book, *Talking About Leaving: Why Undergraduates Leave the Sciences*, Seymour and Hewitt (1997) categorized and ranked the reasons that students abandon science majors at 4-year colleges and universities. In interviews and focus groups, the authors discovered that after loss of interest in science and growing interest in other majors, the third highest ranked reason for leaving science is poor teaching. Over 90% of students who switch out of science—and three quarters of the students who

remain in the science major—say they are concerned about the poor quality of teaching in their science courses. Specifically, students list the lack of faculty–student interaction, "coldness"' of the classroom, lack of preparation and organization, and dullness of presentations as evidence of poor teaching. Students also describe how teaching could be improved in science courses, listing "openness, respect for students, encouragement of discussion, and the sense of discovering things together" (p. 148). In a similar study at highly selective universities, science majors rate their course instruction lower than students with nonscience majors (Strenta, Elliott, Adair, Matier, & Scott, 1994). Furthermore, although most students who switch out of a science major list "interest in another major" as their primary reason for leaving, about 40% of students criticize the poor quality of instruction as cause for leaving science (Strenta et al., 1994).

College student attrition from science, technology, engineering, and mathematics (STEM) majors most often occurs in the first or second year of college (Seymour & Hewitt, 1997). Furthermore, Manis, Thomas, Sloat, and Davis (1989, as cited in Strenta et al., 1994) reported that students' experiences in their freshmen science courses are the most influential in their decision to switch out of their major. In a study on retention in engineering majors, Lichtenstein and colleagues found that poor teaching in preengineering courses can cause

students to think that their engineering courses would be poorly taught, and therefore they contemplate leaving the major (Lichtenstein, Loshbaugh, Claar, Bailey, & Sheppard, 2007). Encouragingly, these authors also found that "a single positive interaction, excitement about a course's teaching and/or content . . . cause a student to confirm his or her choice to stick with engineering" (p. 20). In contrast to the larger scale efforts to retain students in STEM, such as summer bridge sessions, supplemental courses, externally funded undergraduate research programs, and department-wide student mentoring and support systems (Brewe, Kramer, & Sawtelle, 2012; Fortenberry, Sullivan, Jordan, & Knight, 2007; Hsu, Murphy, & Treisman, 2008; Koenig, 2009; Maton, Hrabowski, & Schmitt, 2000), this finding suggests that a single introductory course can have an impact on student persistence in STEM majors. In particular, using interactive, engaging teaching methods could help improve the retention of students in STEM majors. In this paper, we examine the relationship between changing the pedagogy from lecture to Peer Instruction (PI) in an introductory physics course and student retention in STEM majors.

Peer Instruction

PI is an interactive teaching technique that promotes classroom interaction to engage students and address difficult aspects of the material (Crouch & Mazur, 2001; Crouch, Watkins, Fagen, & Mazur, 2007; Mazur, 1997). PI structures time during class around short, conceptual multiple-choice questions, known as ConcepTests. In Figure 1, we show an example ConcepTest from introductory physics. These questions are targeted to address student difficulties and promote student thinking about challenging concepts.

Typically, the instructor starts with a brief presentation or summary of the material to be covered. Then, the focus shifts from instructor to student, as the instructor poses a ConcepTest and asks students to think about the question and related concepts. After 1–2 minutes of thinking, students commit to an individual answer by using clickers, flashcards, a simple raising of hands, or writing down the answer on a piece of paper. If too few students respond with the correct answer, the instructor may revisit the concepts using lecture or try a different ConcepTest. If a large majority of students respond correctly, the instructor typically gives a brief explanation and moves on to the next topic or ConcepTest. If 30–70% of students answer the ConcepTest correctly, the instructor asks students to turn to their neighbors and discuss their answers. Students talk in pairs or small groups and are encouraged to find someone with a different answer. The teaching staff circulates throughout the room to encourage productive discussions and guide student thinking. After several minutes, students answer the same ConcepTest again. The instructor then explains the correct answer and, depending on the student answers, may pose a related ConcepTest or move on to a different topic or concept.
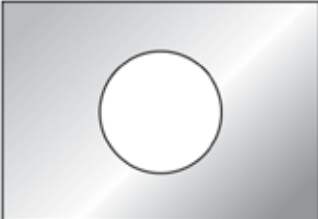
Research in physics education has shown that courses incorporating "activities that yield immediate feedback through discussion with peers and/or instructors" result in higher scores on assessments of students' conceptual understanding than traditional courses (Hake, 1998). Data from introductory physics courses at Harvard University confirmed this finding, showing improved performance in PI courses on conceptual surveys and quantitative problems (Crouch & Mazur, 2001; Mazur, 1997). The increased overall learning gains with the use of PI have not only been found at highly selective institutions. The results were replicated at a community college (Lasry, Mazur, & Watkins, 2008), suggesting that PI is effective with heterogeneous student populations. Furthermore, the positive results of PI are not limited to physics courses. Other studies have shown that PI is useful in improving learning in biology (Knight & Wood, 2005), engineering (Nicol & Boyle, 2003), psychology (Morling, McAuliffe, Cohen, & DiLorenzo, 2008), medicine (Rao & DiCarlo, 2000),

FIGURE 1

An example of a ConcepTest.

Consider a rectangular metal plate with a circular hole in it.

When the plate is uniformly heated, the diameter of the hole

1. increases.
2. stays the same.
3. decreases.

philosophy (Bigelow, Butchart, & Handfield, 2006), and mathematics (Miller, Santana-Vega, & Terrell, 2006).

Methods

In this paper, we examine data from students in the first semester of an introductory calculus-based physics course that is two semesters long for nonmajors at Harvard University during the period 1990–1996. Each year, the course met for 1.5 hours, twice a week, in a large lecture hall, while smaller sections (15–20 students) were led by teaching assistants once a week for 1–2 hours. In 1990, the course was taught using traditional lecture-based methods. In 1991, PI was introduced during the twice-weekly, whole-class meetings. Also at this time, reading quizzes were implemented to encourage students to read before class and, in 1995, the courses began using a research-based textbook developed by Mazur (2014). In all years, the weekly homework consisted of traditional quantitative problems. Starting in 1991, exams included conceptual problems as well as traditional quantitative problems to reinforce the importance of conceptual understanding in learning physics. As PI had not yet been widely disseminated, the introductory physics course was the only course in which students were exposed to PI.

Students were asked at the beginning of their introductory physics courses to indicate their major (first-year students were asked to indicate in which subject they planned to major). We linked these data to students' majors recorded at graduation. We then analyzed the relationship between pedagogy and the fraction of the students who initially indicate that they intend to major in a STEM discipline and then later switch to a non-STEM major.

Our study sample included 105 students in the traditionally taught 1990 course, 101 of whom indicated a STEM major at the start of the course. There were 1,072 PI-taught students in our sample; 997 indicated they were majoring in or intended to major in a STEM discipline. No students in either the traditional course or the PI courses indicated that they were majoring in physics.

In our analysis, we used a chi-square test to compare the proportions of students switching out of STEM majors in the traditional lecture-based course and those courses using PI. We then controlled for differences in students' background and demographics using regression analysis. However, we could not use linear regression, because our dependent variable could only take on the values of 0 or 1—students either stay in a STEM major or switch out of it. Instead, we used logistic regression analysis (Hosmer & Lemeshow, 2000), which uses the log of the odds of switching out of STEM majors as the dependent variable (in $\left[odds = \frac{P}{1-P}\right]$, where P is the probability of switching out of a STEM major), as this transformation allows for a linear relationship with the independent variables. From this analysis we obtained the estimated probability of switching out of a major, given different background characteristics of students and whether they took the traditional or PI courses.

Results

Table 1 shows the percentage of students who switch out of a STEM major, separated by course pedagogy. The proportion of students who were enrolled in the traditionally taught introductory physics course and switched out of a STEM major is more than twice that of students enrolled in the courses taught using PI ($\chi^2 = 5.1$, $p = .02$). Furthermore, the impact of pedagogy on STEM major retention is consistent across both genders.

Figure 2 shows the fluctuations in the percentage of students switching out of STEM majors from year to year. Compared with 1990, when the course was traditionally taught, the percentage of students switching out of STEM majors after taking the PI course is more than 50% smaller. The figure suggests that the results from 1990 are not simply due to yearly fluctuations, but also point to the need to account for the groupings of students by year in our regression models. By using multilevel modeling in the logistic regression analyses, we take into account the random variability between courses in addition to the variability between individual students.

In Figure 3 we graphically represent the results from logistic regression analysis by plotting the fitted probabilities of switching out of a STEM major. As the figure shows, when we control for pedagogy and SAT math scores, the odds of freshmen switching out of a STEM major are predicted to be about 10 times those of upperclassmen ($p < .001$). Furthermore, students with higher SAT math scores are less likely to

TABLE 1

Percentage of students who switch out of STEM majors, by pedagogy and by gender ($N_{trad} = 101$; $N_{PI} = 997$).

| Instruction	Total	Male	Female
Traditional	0.11	0.11	0.10
PI	0.05	0.06	0.05

Note: PI = Peer Instruction.

switch out of science than those with lower SAT scores; for every 100-point decrease in SAT score, the fitted odds that a student will switch out of a STEM major nearly double ($p < .05$). Finally, reflecting what we already saw in Figure 2, students in a PI course are, on average, half as likely to switch out of STEM majors as those in the traditionally taught course ($p < .05$), at every level of SAT math scores.

Discussion

The results presented here provide compelling evidence that a single course can have a significant long-term impact on the retention of students in STEM majors. Previous research on retention in the sciences offers compelling reasons why PI may be well suited to positively impact students both during the course and beyond. By reforming the classroom environment, PI addresses many of the complaints that students leaving STEM majors have expressed about teaching in introductory science and engineering courses. By incorporating and structuring peer discussions, students have more opportunities to get to know each other and share ideas, perhaps reducing the "coldness" and increasing the "openness" of the introductory science classroom. During these discussions, the instructor also has the opportunity to listen and participate, providing for greater faculty–student interaction. Additionally, much of class time is set aside for thinking about conceptual questions and discussing ideas with fellow classmates, which can make class time more engaging and less "dull." By addressing these issues raised by students leaving the sciences, PI may create "a single positive interaction, excitement about a course's teaching and/or content" for students that research has shown can confirm their choice to remain in a STEM major (Lich-
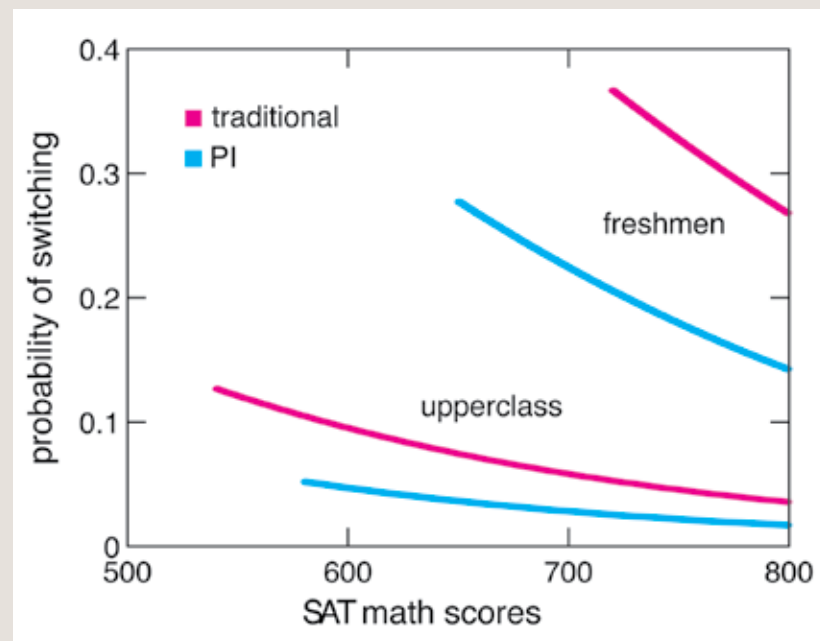
FIGURE 2

Percentages of students switching out of STEM majors by year. PI = Peer Instruction.
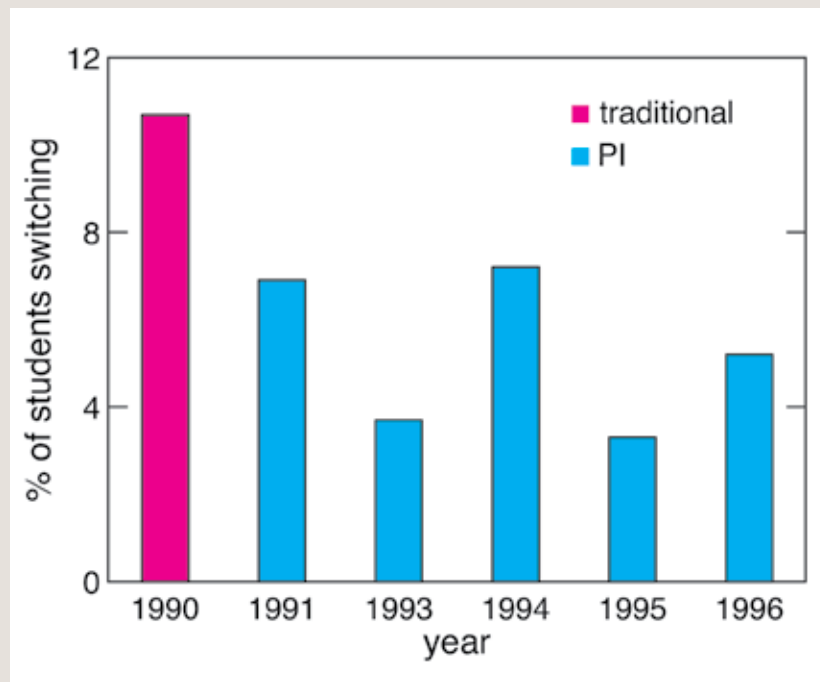
FIGURE 3

Probability that a student will switch out of STEM majors, by pedagogy, year in school, and SAT math scores. PI = Peer Instruction.

tenstein et al., 2007).

In addition to addressing student concerns about introductory science courses, there are other reasons to believe that PI positively impacts student retention. During class, instructors receive constant feedback about students' ideas and progress, which allows them to better tailor their instruction to their students' needs. PI also creates opportunities for students to help each other. Research on the impact of student discussions has shown that they can improve student performance even among student groups who did not have the correct answer (Smith et al., 2009). These benefits of PI can promote greater student learning of physics concepts; indeed, data from conceptual surveys have consistently shown higher posttest scores and gains on courses taught using interactive engagement techniques (Hake, 1998). Furthermore, students have greater opportunities to develop and practice critical skills in scientific argumentation, such as asking questions, articulating their ideas, and justifying their claims to their peers (Driver, Newton, & Osborne, 2000). Students also receive continued feedback on their own performance, allowing them to better assess and monitor their own understanding. With more opportunities to improve their conceptual understanding, scientific communication practices, and metacognitive skills, students who take a PI course may be better prepared for intermediate and advanced science courses, thereby increasing the likelihood that they will persist in a STEM major. Finally, pedagogies that engage students in disciplinary practices have been shown to increase self-efficacy, which in turn increases students' pursuit of a career in this field (Lucas & Barge, 2010; Mau, 2003).

Given the small number of courses and unique student population used in our study, further research is needed to examine whether PI and other interactive-engagement techniques result in similar increases in student retention in STEM majors at more diverse institutions and in more recent years. In particular, our results point to the need to study the impact of PI in courses that serve more underclassmen; in our study the effects of pedagogy were particularly notable with these students as they were more likely to switch out of a STEM major early in their college career. In addition, research has shown that there is variation in how instructors implement PI, which can result in different student perceptions of the classroom (James & Willoughby, 2011; Turpen & Finkelstein, 2009, 2010) and change the nature of the relationship between pedagogy and student retention. Although this paper examines the impact of PI, there are other pedagogies that incorporate the beneficial features described here, such as eliciting and responding to students' ideas and encouraging student discussions (e.g., Brewe, 2008; Etkina & Van Heuvelen, 2007; McDermott, Schaffer, & University of Washington Physics Education Group, 2002; Redish, 2003) and are therefore likely to obtain similar results. As more instructors turn to new pedagogies in a wide range of higher education classroom settings (Sevian & Robinson, 2011), these promising results invite further examinations on the longitudinal effects of individual course reforms. ∎

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