Improving Undergraduate Science and Engineering Instruction at a Research University: Challenges and Solutions

Angela M. Kelly[1], Mónica F. Bugallo[2], Ghada Nehmeh[3], Jennifer Gatz[4]

Abstract

This study addressed the rationale and cultural and institutional challenges associated with implementing reformed science and engineering teaching practices, student impacts related to a pilot program in student-centered science learning, and recommendations for broadening support for novel learning contexts among key stakeholders. Undergraduate science and engineering instruction has often been characterized by a traditional pedagogical approach, where instructor-centered contexts diminish active engagement, attitudes towards science, and comprehension. Furthermore, important groups of students (women, underrepresented minorities, and high school teachers) have not been well served by traditional models of science and engineering teaching. The context for this study is a research university in the U.S., where students shared their views on their introductory science and engineering classroom experiences. Survey data indicated a perceived lack of alignment between theoretical and experimental aspects of the courses, and a general negative view towards instructor-centered approaches. Consequently, a new instructional model was implemented to promote active learning and peer instruction. Students in introductory physics were given the option to enroll in Studio Physics, with more hands-on learning, collaborative problem solving, and instructor support. Lecture, laboratory, and recitation were seamlessly integrated to facilitate frequent student interactions where science knowledge was constructed socially. Pre-service science teachers were recruited to serve as teaching assistants, improving pedagogical skills under the supervision of faculty while interacting with students. Data revealed improved student engagement, self-efficacy, physics sense making, and recognition of the relevance of physics in their everyday lives. However, such novel pedagogical approaches often encounter resistance without sustained institutional support. Implications for the development and implementation of undergraduate science and engineering teaching reforms are discussed.

Keywords: *Engineering education, Physics education research, Science education, Teacher education, Teaching reform, Undergraduate education;*

1. Introduction

The call for improvement in STEM education in the United States has reached epic proportions in recent years. In their widely publicized report, *Rising Above the Gathering Storm*, the National Academies has called for vast changes in STEM education [1]. Among the most pressing issues that the STEM education community has been trying to address are students' inadequate preparation for college-level STEM coursework, the widening of the achievement gap among underrepresented groups, and the low numbers of students who major in science and mathematics [2].

A recent report from the National Research Council, *Adapting to a Changing World: Challenges and Opportunities in Undergraduate Physics Education* [3], examined the status of physics education and provided recommendations for improvement. One major challenge is that most students have not gained a genuine understanding of physics concepts, practices of inquiry, and scientific habits of mind used in the discipline. Also, important groups of students (women, underrepresented minorities, prospective high school teachers) remained underserved by the traditional dominant paradigm of physics teaching. The American Physical Society has stated that the best way to remediate these issues is to improve introductory physics teaching and learning [4]. Reformed pedagogical practices in introductory STEM coursework have been shown to improve students' classroom experiences and persistence in STEM majors and careers [5,6]. This pilot study replicates and expands upon a research-based instructional model that resulted in innovative reforms at many campuses across the U.S., which reported transformative practices that have improved student learning, retention in STEM majors, attendance, and attitudes towards science [7,8,9].

[1] Stony Brook University, USA
[2] Stony Brook University, USA
[3] Stony Brook University, USA
[4] Stony Brook University, USA

2. Methods

The pilot study employed a proof of concept approach in examining student engagement and attitudes in introductory physics courses for life science, physical science, and engineering majors at a research university in the U. S. The exploratory design utilized data from a treatment group in a newly designed Studio Physics classroom model, and compared some variables to previous studies, as seen in similar pattern matching nonequivalent dependent variables designs [10].

The context for the study was a curricular model whereby undergraduate students learned physics in a smaller classroom environment, with more hands-on activities, peer problem solving, and instructor support. The four-credit class met for 100 minutes three times per week. The new laboratory equipment enabled repeated trials in experiments and immediate data analysis. The new classroom design facilitated frequent student interactions through clicker questions, group problem solving, and class discussion. The physical classroom space has eight tables that seat nine students each, and an instructor's station in the front of the room (Figure 1). The placement of this station allowed for the instructors to move freely among students while leading discussions, and it discouraged the traditional lecture format. PowerPoint slides and demonstrations were projected onto 6 screens positioned around the perimeter of the room. Students stood at various times during class to work out solutions collaboratively at white boards mounted along the perimeter. There were iPads and Vernier LabQuest devices on each table for laboratory exercises, where data were collected and analyzed electronically. Graduate and undergraduate teaching assistants facilitated problem solving and laboratory work under the direct supervision of physics faculty. Graduate TAs were recruited from the Master of Arts in Teaching (MAT) Program, bringing superior pedagogical skills to the classroom. High performing undergraduate TAs were also recruited to participate and earned teaching practicum credit. Two sections of 72 students each were offered each semester. The model was evaluated with preliminary data collected over one semester.

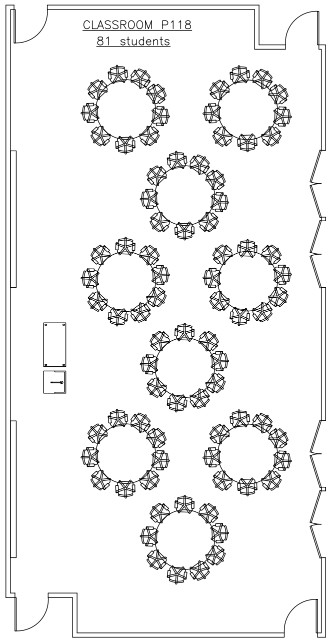

Fig. 1. Model of Studio Physics classroom

Students were recruited for the pilot course from several bridge programs at the university that targeted traditionally underserved students. Advisors in the College of Arts & Sciences and the College of Engineering & Applied Sciences were consulted to maximize student participation. Students were given a choice whether to enroll in Studio Physics, traditional, or online offerings.

3. Results

Classroom observations of Studio Physics were performed. Taped class sessions were coded to assess the level of student engagement; the coding instrument was the *Classroom Observation Protocol for Undergraduate STEM* (COPUS) [11]. Six 60-minute Studio Physics class segments were analyzed. Classes were selected when laboratory exercises were not taught, which provided the most accurate comparison with traditional classes. Data revealed that students were actively engaged an average of 50% of class time (Figure 2). Engagement was measured by non-listening tasks such as individual thinking, answering questions posed by the instructor, participating in group work at tables or white boards, answering clicker questions individually or in groups, and asking questions of the instructors.

Traditional lecture-based classes have little opportunity for active learning. In a recent study at the University of Maine and the University of British Columbia, it was determined that students were passively listening more than 90% of the time during typical lectures. In courses that emphasized active learning and peer discussion, the results of the study mirrored what was observed in Stony Brook Studio Physics classes [11].

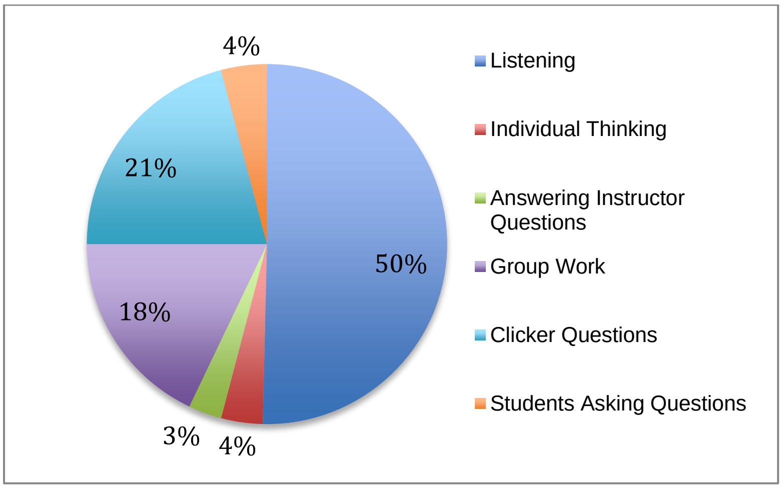

Fig. 2. Student actions during typical Studio Physics classes

Attitudes towards physics and physics learning were measured at the start and end of the semester in Studio Physics. The purpose was to evaluate how students' beliefs about physics were influenced by their particular classroom experience. The instrument was the *Colorado Learning Attitudes about Science Survey* (CLASS) [12], which measures personal interest in physics, real world connections, problem solving confidence, and sensemaking/effort. A sub-group of students responded on a Likert scale and sample statements are included in Table 1. They reported an increase in their ability to solve physics problems with multiple strategies, increased problem solving confidence, and a greater tendency to relate physics to their everyday lives.

Table 1. Studio Physics: Students' attitudinal shifts (*N*=16)

Category	Pre-Survey Agree/Neutral/ Disagree (percentage)			Post-Survey Agree/Neutral/ Disagree			Shift Agree/Disagree	
	A	N	D	A	N	D	A	D
Sensemaking/Effort								
• There are times I solve a physics problem more than one way to help my understanding.	44	44	12	56	25	19	+12	+7
Problem Solving Confidence								
• I can usually figure out a way to solve physics problems.	56	19	25	69	13	19	+13	-6
Personal Interest/Real World Connections								
• I think about the physics I experience in everyday life.	50	25	25	63	31	6	+13	-19
• To understand physics, I sometimes think about my personal experiences and relate them to the topic being analyzed.	56	19	25	63	19	19	+7	-6

4. Conclusions

4.1 Recommendations and implications for adoption of Studio Physics model

The newly designed Studio Physics model provided more seamless integration between theory and practical laboratory experiences. However, the implementation of the Studio Physics model did not come without challenges. As with most research universities, lecture, laboratory, and recitation are segmented and often do not align chronologically in terms of disciplinary content. Furthermore, traditional classrooms have employed a lecture-based approach that may limit comprehension for some students [8,9].

To maximize institutional buy-in, several strategies were employed. First, models at other universities provided a strong rationale and data for replication at the study site [5,7,9]. The researchers provided data to demonstrate how the model was consistent with the core mission of the university. By doing so, funding was secured by the University Parents Fund for initial renovation and laboratory equipment costs, and the Howard Hughes Medical Institute provided funding for curriculum development. Secondly, with the support of the Physics Chair, senior physics faculty were recruited to teach the course in teams. This approach established rigor and maintained high quality to ensure at least equivalent outcomes in terms of physics learning. Third, ongoing data collection provided evaluative feedback to justify continuation and potential expansion of the model. Future data analysis will include control and treatment group physics knowledge comparisons along with qualitative studies with key stakeholders (students, graduate students, faculty).
Future work will also include expansion of the model, which has been limited to date due to faculty and resource demands. The model has the potential to be implemented in higher level classes, as well as additional sections of introductory courses. Its initial success provides promise for replication in other science and engineering courses to promote student learning and persistence in undergraduate STEM majors.

Funding for this study was provided by the National Science Foundation [7686640].

References

[1] National Academies of Sciences. “Rising above the gathering storm,” Washington, DC, National Academic Press, 2007.

[2] President’s Council of Advisors on Science and Technology [PCAST]. “Engage to excel: Producing one million additional college graduates with degrees in science, technology, engineering, and mathematics,” Washington, DC, PCAST, 2012.

[3] National Research Council. “Adapting to a changing world: Challenges and opportunities in undergraduate physics education,” Washington, DC, National Academies of Sciences, 2013.

[4] Popkin, G. “History of APS involvement in education,” College Park, MD, American Physical Society, 2012.

[5] Brewe, E. “Modeling theory applied: Modeling instruction in introductory physics,” American Journal of Physics, 76(12), 2008, pp. 1155-1160.

[6] Handelsman, J., Elbert-May, D., Beichner, R., Bruns, P., Chang, A., DeHaan, R., Gentile, J., Lauffer, S., Stewart, J., Tilghman, S., & Wood, W.B. “Scientific teaching,” Science, 304(5670), 2004, pp. 521-522.

[7] Dori, Y.J., & Belcher, J. “How does Technology-Enabled Active Learning affect undergraduate students’ understanding of electromagnetism concepts?” Journal of the Learning Sciences, 14(2), 2005, pp. 243-279.

[8] Watkins, J., & Mazur, E. “Retaining students in science, technology, engineering, and mathematics (STEM) majors,” Journal of College Science Teaching, 42(5), 2013, pp. 36-41.

[9] Hake, R.R. “Interactive engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses,” American Journal of Physics, 66(1), 1998, pp. 64-74.

[10] Coryn, C. L. S., & Hobson, K. A. “Using nonequivalent dependent variables to reduce internal validity threats in quasi-experiments: Rationale, history, and examples from practice,” New Directions for Evaluation,” 131, 2011, pp. 31-39.

[11] Smith, M. K., Jones, F. H., Gilbert, S. L., & Wieman, C. E. “The Classroom Observation Protocol for Undergraduate STEM (COPUS): A new instrument to characterize university STEM classroom practices,” CBE – Life Sciences, 12, 2013, pp. 618-627.

[12] Adams, W. K., Perkins, K. K., Podolefsky, N. S., Dubson, M., Finkelstein, N. D., & Wieman, C. E. “New instrument for measuring student beliefs about physics and learning physics: The Colorado Learning Attitudes about Science Survey,” Physical Review Special Topics - Physics Education Research, *2*(1), 2006, 010101.