Student Success in Introductory Physics

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Abstract
The Department of Physics and Astronomy at CSU Long Beach have instituted several reforms in the last decade to support student success across the engineering and physical science fields. First, we have chosen a curriculum in our introductory courses emphasizing a small set of fundamental principles and problem solving. We support the development of these problem solving and critical thinking skills through a classroom response system (I>Clicker), a peer-instruction program in which upper division physics majors model these skills in both the mechanics and the electricity and magnetism laboratories, and through the creation of "engineering-honors" themed sections of these courses. Lastly, we are experimenting with a structured online collaborative system, in which students cooperatively solve physics problems and develop teamwork and leadership skills at an early point in their education. We report on data generated in our introductory physics courses on these dimensions of student success.

Overview
The Department of Physics and Astronomy at CSU Long Beach has been engaged in a decade-long campaign to reform and tune the first-year physics sequence taken by the vast majority of engineering students, calculus-based mechanics (PHYS 151) and electricity and magnetism (PHYS 152). Our point of view has been that these courses should serve as a first, positive experience in STEM coursework, rather than as barriers to students seeking engineering degrees and careers. To this end, the course revision was done to actively engage students in the discipline of physics as practiced by physicists. While the content of our courses has not changed, we approach the subject from a modern point of view, in which the speed of light is an important barrier, and in which mater is made from atoms. Coupled with developing softer yet vital career skills in collaboration and teamwork, this approach has dramatically increased not only the passing rate of these courses, but has also dramatically (and positively) affected students' perceptions of themselves and what they are doing in a STEM major. We describe below the reform curriculum we have adopted, an important peer-learning strategy employed in the department, our peer-to-peer support system, and then the impact of our honors sections before displaying assessment data from these courses.

Matter and Interactions
The *Matter and Interactions* curriculum has been in development in the Physics Education Research Group of North Carolina State University since 2003.[1] A rich thread of approaching problems through computer programming in VPython undergirds the course, freeing the instructor from dealing with the highly restricted set of analytically solvable problems which are approachable with first-year physics methods. Thus, the approach is closely related to finite element methods students will use intensively further along in their engineering studies. Thus, in adopting a computational tool, we are able to concentrate on the logical structure of the solutions to problems, rather than tempting student to remember long lists of analytic results (along with

their ranges of applicability). The course thus reduces to three fundamental concepts (having to do with momentum, energy, and angular momentum) and how those concepts fit together to describe realistic interactions between cars, galaxies, or even elementary particles.

This approach focuses on how practicing physicists actually use these fundamental ideas in their own academic work. We have found that maintaining high student involvement and enthusiasm in the course is related to both how students see these ideas being used in their further studies, but also in seeing an expert in the field use these ideas in their own right. The "flavor" of doing physics the way physicists to do is strongly enticing for students, who otherwise experience this subject as too "theoretical" and removed from their own ambitions and lives. Indeed, the number of physics-engineering double majors has increased steadily since we have adopted this curriculum. Given that there are a high proportion of students from underrepresented groups attempting engineering degrees at CSULB, our reformed curriculum is enhancing opportunities available for this vital group of students.

I>Clicker

The vast majority of students at CSULB take these introductory courses in a large lecture format, with class sizes ranging from 60-180. Maintaining consistent attendance and engagement of students in these large environments and providing instructors feedback about how students are understanding lecture components is a perennial issue in large-format general education courses. We have to a large degree met both goals through integrating a classroom response system, in this case with the CSULB campus standard I>Cicker.[2] Here, lectures are broken up by simple, but probing, multiple choice questions that each students answers with a semi-anonymous press of a button. There is ample time for students to discuss their answers while a standard timer is counting down, and there is a large proportion of participation credit associated with the device. Thus, the device is not used to perform high-stakes assessments (in the form of real-time multiple-choice exams) but rather gives students a chance to digest and use the information that has just been introduced. In this manner, an instructor can decide on the fly if a concept needs reinforcement, or if the topic has been sufficiently well understood by the class as a whole. Thus, the clickers are used to guide instruction on a day-to-day, and minute-to-minute basis in the classroom.

Learning Assistants

Starting in 2010, the department has instituted a "Learning Assistant" program based upon the model established by the University of Colorado.[3] In our program, promising students in either PHYS 151 or PHYS 152 are encouraged to take an upper-division training course in physics pedagogy, PHYS 390 "Exploring Physics Teaching". This course counts toward physics upper-division elective credit in all physics degree programs. In this course, students are trained in asking probing questions and in effective interactions as an instructor. They spend six weeks assisting students in the PHYS 151 laboratory, and ten weeks in the college's student supporting center offering free walk-in tutoring for PHYS 151. Upon completing the course with at least a "B" grade, they are eligible to be hired as a "Learning Assistant" in the department. These are not "teaching assistants" in that they have absolutely no grading or evaluation duties, and they are not responsible for creating lecture content as a Supplemental Instructor is required to do. Their basic role is to ask and answer questions, and even more importantly to know which questions must be answered with other questions in order to advance learning. We have placed

Learning Assistants in PHYS 151 and PHYS 152, and they are being deployed in the upper-division courses that physics-engineering double majors take most often, and have the most difficulty with (PHYS 310 “Analytic Mechanics”, PHYS 350 “Modern Physics” and PHYS 340A “Electricity and Magnetism”). Students in these courses see their Learning Assistants as peers in whom they can more easily confide confusion, and more quickly take risks with answers that are incomplete or based on misconceptions. Interacting with Learning Assistants has a profound impact on how we achieve all of our course goals.

Social Homework and Group Problem-Solving

The STEM professions are characterized by highly collaborative workflows. Working effectively with highly-trained and high-functioning peers from vastly different social, ethnic, and national backgrounds is a requirement for succeeding in today’s STEM workforce. We are implementing on a trial basis an asynchronous web-technology that gives students at the very start of their technical education the experience of working collaboratively in a “research group”. This so-called “Social Homework” system allows an instructor to assign students into working groups with specific problems to solve, and with specified roles for each group member to perform.[4] It is based on the ground-breaking work on cooperative group problem-solving in the University of Minnesota’s Physics education research.[5] The groups generally are stable for an entire semester, and students get a part of their grade from their individual work, but also from the group effort as a whole. The individual roles are modeled on the problem-solving strategy used in our reform Matter and Interactions curriculum and also mimic those roles that are performed in a real STEM research group. Each problem is couched in the same language as a “Request for Proposals” and the deliverable at the end of the process is a properly formatted solution which is shared with the entire class. These “deliverables” constitute a student generated “wiki” that everyone can consult to help in completing their individual homework problems. Being accountable to a group, depending on a group, and most importantly evaluating the quality of a group’s performance (quality control) are the new elements this system adds to the PHYS 151 and 152 sequences. We have strong evidence that social homework increases the integrity of the educational process, and those students who are in the C-D grade range benefit substantially.

Honors Sections

Completion of degrees in a timely manner is rightly an important priority for any public institution of higher learning. Thus a lot of faculty attention and administrative support goes toward helping students who are struggling complete these, admittedly, quite hard STEM degrees. Seeing that students who are excelling get the most from their degrees is likewise an important priority, and we have created engineering-honors sections of PHYS 151 and 152. These sections use both the Matter and Interactions curriculum, and social homework is being implemented on a trial basis in these courses. These are small sections composed entirely of engineering honors students and students who intend to become physics majors. Thus, we have a high-performing group of extremely well motivated students. These sections are small (less than a sixth of the size of an ordinary large lecture in the department) and are taught in technology-enhanced “Active Learning” classrooms on campus. Here, students sit at tables of eight, with a plasma display showing material from the instructor. The wall of the room can be written upon from floor to ceiling with ordinary whiteboard markers. An important part of the honors course is a face-to-face experience in solving challenging problems in a collaborative environment. While it is too early to discuss the outcome of the honors sections, we are confident that the results will be positive and similar qualitatively to the inclusion of "Social Homework" in the regular sections due to the close interactions between students with one another and with the teacher.

Results

The biggest institutional evidence of success in our efforts is that the introductory physics sequence is no longer a gateway course with a low completion rate. In the last four semesters, the D, W, F rate in this course has fluctuated narrowly in the 10% range, without sacrificing the rigor of the material. In a sense, introducing computational methods and modern concepts and methods has made the course more difficult, but student performance is measured in a highly diverse set of measures (content in exams, group skills in the social homework, laboratory work, and homework, for example). Thus, even with the more challenging curriculum, students have a fair shot at learning the material, and passing these classes.

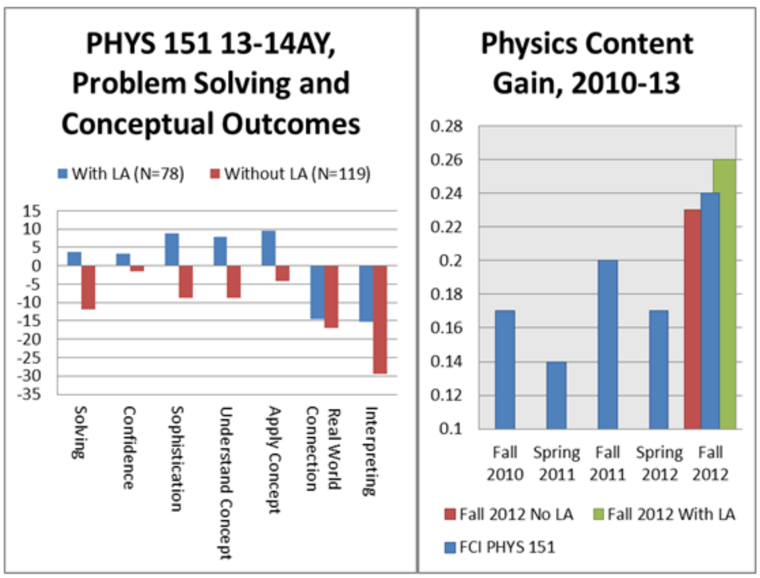

Figure 1. Learning Assistant Impact in PHYS 151.

In figure 1 we present our main evidence for student success in PHYS 151. There are two graphs, each showing the results of a pre/post "value added" measurement of student performance and attitudes in PHYS 151. On the left we present the measurement of several dimensions of STEM "practice" from an instrument developed at Colorado: the Colorado Learning Attitudes About Science Survey (CLASS).[6] This is a 42 item instrument scored on a Likert scale and normalized to the responses physics faculty make to the same items. These items are not physics problems per se, but are meta statements about how problems are approached and interpreted, and thus provides a direct measure of critical thinking skills across its many dimensions. While we have work to do to support students connecting their physics studies to the real world and in interpreting their solutions, when we add Learning Assistants to the laboratory sections, problem solving across its many dimensions is remarkably enhanced. Additionally, the Force Concept Inventory[7] indicates that in the first semester in which we had large LA coverage, our measure of mechanics content mastery is large when LA's are present (green bar) and is improved even in lab sections without LA's (as a result of their drop-in tutoring and social interaction through the Social Homework tool). While data from Spring and Fall 2013 are not yet fully analyzed, there are indications that these gains are enhanced in the honors sections we have introduced.

Indeed, we can make the claim that all of the elements we have introduced (M&I style homework, laboratory work, Social Homework, I>Clickers, and problem solving exams), the Social Homework (SHW below) is the “glue” that makes the course intellectually consistent. Before experimenting with SHW, the r*r correlation value between the M&I homework and, for example, the course exams, was rather weak, on the order of 0.1, meaning that completing the homework successfully explains 10% of the exam grade performance for an individual student. As in Table 1, the correlations between various course elements is now well above statistical significance level, with extremely strong correlations, and the strongest correlations between the SHW score and all of the others.

Table 1. Correlations between different course grades, PHYS 151, Spring 2013.

	M&I	*Lab*	***SHW***	*Clicker*	*Exam1*	*Exam2*
M&I	1					
Lab	0.504341	1				
SHW	**0.668322**	**0.483636**	**1**			
Clicker	0.502102	0.480227	**0.560495**	1		
Exam I	0.304513	0.387333	**0.290939**	0.252759	1	
Exam2	0.615823	0.531764	**0.572702**	0.392227	0.444384	1

Thus, we are confident that we have constructed a sound curriculum that prepares rather than filters prospective engineering students for their further studies.

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