AC 2009-455: SUPPORTING STUDENTS IN PHYS 111: A CRITICAL GATEWAY TO ENGINEERING CAREER PATHS

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Supporting Students in Physics 111: A Critical Gateway to Engineering Career Paths*

This project is funded through a STEP grant from the National Science Foundation (NSF) supporting a multi-intervention initiative to attract high school students and put more STEM graduates into the STEM career pipeline, with a focus on women and underrepresented minorities. A key component of this collaborative effort among the West Virginia University's College of Engineering and Mineral Resources, College of Human Resources and Education, and Eberly College of Arts and Sciences involves retaining students already in the educational pipeline toward STEM careers. As we strive to retain students in engineering career paths, we recognized "gateway" courses. Physics 111 is one of these courses where students struggle, often leading to the unfortunate outcome that they leave engineering degree/career paths. During the Fall 2008 semester at WVU, only 35% of those students enrolling in Physics 111 completed the course with a C or better. The remaining 65% who earned D's, F's, or simply withdrew, are faced with the decision of whether to repeat the course or switch to a degree path that does not require Physics. Those who opt to avoid Physics 111 will not earn engineering degrees. The situation is similar at universities across the nation. Physics is a challenge that all future engineers must conquer, a challenge that too often becomes a barrier.

Physics instruction at many institutions follows traditional "chalk-and-talk" pedagogical models for the field. Students attend large lecture classes presented by faculty with expert understanding of the nuances of force and dynamics. A great deal of material is presented in a short amount of time with the expectations that students will digest that material later. Between lectures, students participate in lab classes led by graduate students where they conduct traditional physics experiments designed to illustrate key physics principles. Faculty trained in these same traditional formats assume students read their texts carefully, struggle to understand material from lecture and text as they work through their lab exercises, and come back to class prepared to move on to more challenging conceptual material. However, there is strong evidence in the literature and from our own experience at WVU (65% DFW rate in Physics 111) that this approach is not working well for many students[1,2].

The conceptual challenges presented by physics material are well documented in the literature. These challenges appear most often as misconceptions students of physics bring to the introductory classroom[3,4]. Misconceptions so deeply rooted that even great thinkers of the past were known to hold them[5]. The most foundational of these misconceptions involve the Newtonian concept of force. The Newtonian concept of force is foundational to physics as well as to most concepts in engineering. The literature clearly establishes misconceptions of force as underlying causes of difficulty acquiring physics content[6,7]. Furthermore, this same research literature demonstrates that students' misconceptions are resistant to change even in the face of instruction the specifically focuses on helping students identify their own misconceptions.

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The pedagogical challenge for physics instructors is clear. Students come with pervasive deep-rooted misconceptions about how the most foundational physics principles work. Traditional approaches to moving students beyond these misconceptions appear relatively inadequate. A variety of innovative approaches have been tried with varying degrees of success[8,9,10,11].

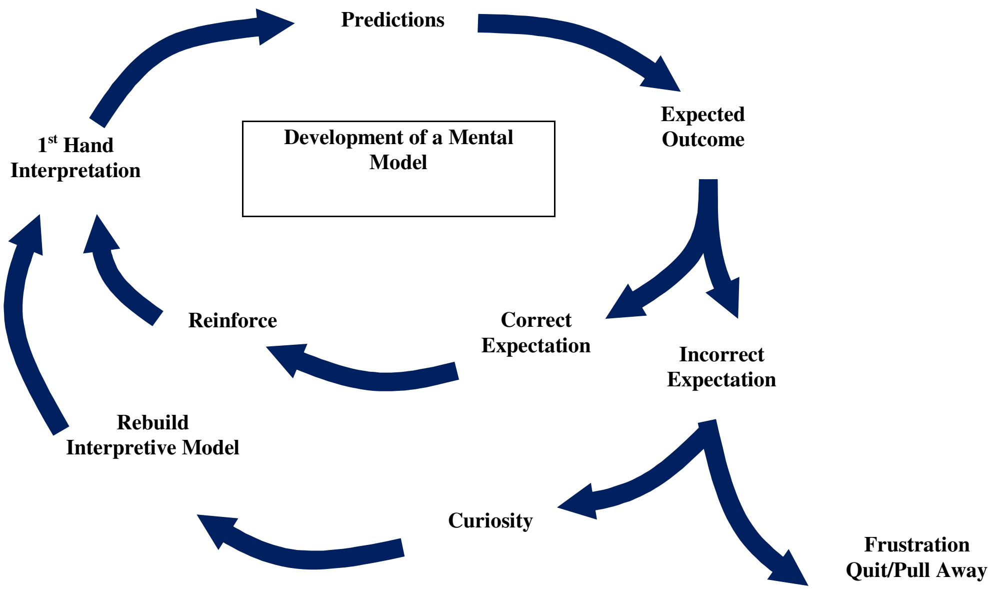
One important part of WVU's "Engineers of Tomorrow" (EoT) project is mentorship, or peer influence defined loosely as a structured, informal relationship among high school, engineering undergraduate, or graduate students for the purpose of sharing information about college life, college courses, career choices, and engineering as a profession. The peer mentor in this case was an engineering graduate student who was age- and major-appropriate (recently completed undergraduate Engineering degree at WVU), culture-appropriate (Appalachian-born and raised); and skill-appropriate (struggled with but eventually excelled in undergraduate engineering program). Mentorship channels were interpersonal (face-to-face) in the physics education intervention described here, but also included virtual communities such as FaceBook. Evidence of the efficacy of the larger Social Stress Model adapted for Appalachia for the EoT project is discussed elsewhere[12]. The focus of this paper is on examining the impact of an innovative approach to supporting students in Physics 111, an approach that utilized peer mentoring among other elements.

One rigorous approach to assessing instructional impact on student misconceptions in physics involves the Force Concept Inventory. "The *Force Concept Inventory* (FCI) is a multiple-choice 'test' designed to assess student understanding of the *most basic* concepts in Newtonian mechanics. The FCI can be used for several different purposes, but the most important one is to evaluate the effectiveness of instruction."[6,7]. The FCI has been validated and utilized in pretest/posttest formats with appropriate comparison groups in a wide variety of contexts from high school through graduate study[13,6]. Building on our review of this literature, we utilized the Force Concept Inventory (FCI) to examine Physics 111 students' understandings before and after completing the course. We instituted innovative techniques to support a subset of Physics 111 students, and utilized FCI scores to determine whether those who received our intervention outperformed those receiving more traditional approaches.

Recruiting Students to the Intervention Course

We recruited students to participate in our intervention from a random selection of 3 laboratory sections. All students in each of these sections received both pre and post semester evaluations via the FCI exam as part of their lab activities, but only those who self-selected received the intervention. Because our intervention involved students enrolling in an "extra course", which they unanimously did not want to do on the face of it, recruitment to participate required significant effort. Prior to the students receiving the pretest FCI, time was spent in lab addressing the philosophy behind physics and engineering education before developing the idea of a Mental Model with the students. The figure below was presented to each lab section as a means of introducing students to the pedagogical approach behind the intervention course.

Figure 1: Development of Mental Model Approach Utilized to Recruit for Intervention Group



The model was introduced to students as follows: Basic associations are made by individuals while developing a 1st-Hand Interpretation of the physical world very early in life. This individual interpretation lays the foundation for constructing an individual Mental Model of the universe, from which Predictions are made. Expectation is generated from prediction and can be tested against additional experience. Interpretations are reinforced by outcomes that correspond with expectations. However, this is not always the case. When a model fails to make an accurate prediction, there are two likely responses. Frustration and curiosity lead students in different directions. Those frustrated are easily drawn toward giving up on the problem, thus relying on their 1st-Hand Interpretation and its misconceptions for solutions. But those curious will eventually find the source of the discrepancy, using it to reconstruct and strengthen the interpretive model.

Potential participants were told that the intervention course would involve discussion to open individual student models to the class as a whole. One student views the problem his way, another sees it from a different angle. Students would spend much of their time in discussion before the class, explaining their view and posing questions to the group. Likewise, members of the class would be expected to openly offer alternative methods or viewpoints. In this way, the instructor and class members would iteratively remove misconceptions from student models, developing more clear visualizations of each problem rather than focusing on memorized solutions.

After taking the introductory FCI exam, students were asked to comment as to their interest in participating in the intervention course on the cover of their exam booklet. Additionally, students within the lowest quartile of scores from the pretest FCI results and students recommended by their Physics 111 professors were targeted for outreach. Outreach conducted by the intervention course instructor included utilizing Facebook online social networks and encouragement of word-of-mouth promotion among the students.

A Typical Class Session for the Intervention Course

Our intervention included meeting in small groups twice a week at the Engineering College, drawing on students' collective pre-engineering experience while developing physics understanding. Graduate engineering students, selected to be both age and Appalachian-culture similar to the students in Physics 111, facilitated discussion around individual students' mental models.

Sessions typically began with the instructor opening the floor to questions concerning assigned problems from Physics 111 lecture, lab, or other relevant material. Students' ineffective methods for problem solving were routinely addressed. Primarily, these consist of poorly constructed or generally unclear Free Body Diagrams, depicting unnecessary and confusing information. Students were encouraged to habitually redraw their system, focusing on creating clean and simple diagrams.

Still lingering from their high school experience is a uniquely disadvantaged method described as "collecting the knowns," where students will read through the problem as much as is necessary solely to collect any given values. Then our students would compare those known values among several equations, matching for any variables that might be solved with the given information. When questioned, these students could rarely describe the circumstances of their individual problem solutions. This is an indicator of a "plug-n-chug" mentality, which has shown throughout the intervention course to be a very difficult habit to break. Students repeating the question, "What equation should I use?", was also indicative of this complicated mindset.

Methods that have produced positive results in the intervention course center on participatory behavior. Interaction through open discussion among students and with the instructor developed an atmosphere that allowed students to overcome their anxieties. This environment was essential to students gaining an ability to work through problems publically at the chalkboard. In response, those remaining seated would consistently pose questions or offer alternative viewpoints for the problem at hand. These actions would often create a sustainable dialog requiring only minimal input from the instructor for periods of time. From the vantage point of the instructor, the participating students had begun to enjoy the process of logically realizing their own solutions, as opposed to relying on that from the instructor. The interactivity of the students was central to encouraging the development of more appropriate and enjoyable work habits.

How We Measured Success and What We Found

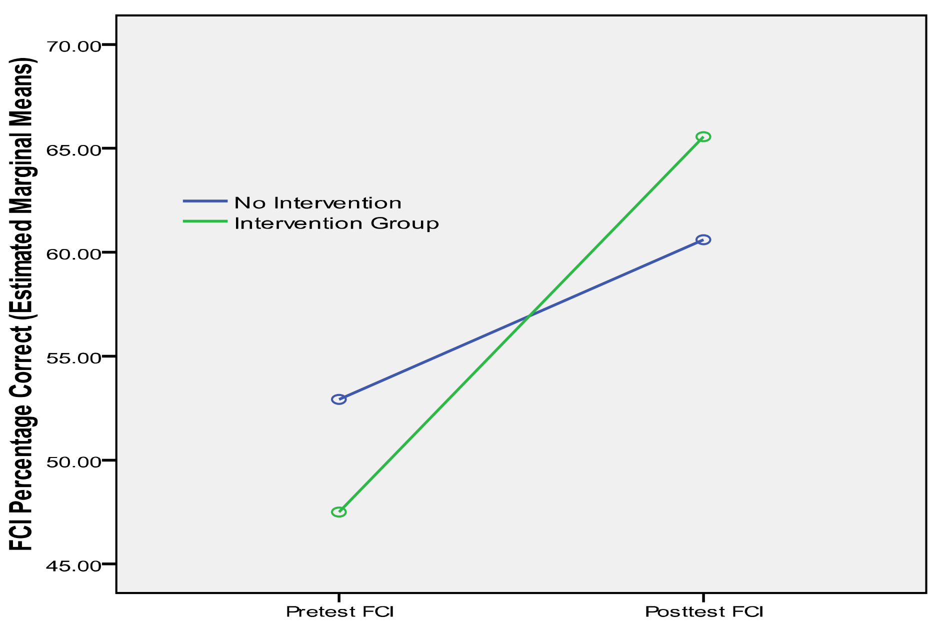
The Force Concept Inventory is composed of 30 multiple choice items designed to make students choose between Newtonian mechanics and commonsense alternatives [6 7]. The Newtonian concepts addressed by groups of items on the FCI include Kinematics, the First Law, the Second Law, the Third Law, the Superposition Principle, and Kinds of Force. Incorrect answers on specific items are indicative of specific constellations of misconception held by a particular student. The authors of the FCI instrument argued that 80% should be considered the minimum threshold for "Newtonian thinkers". Further, it is especially critical to address misconceptions for beginning students with scores below 60% overall. [6,7,14]

Table 1. Force Concept Inventory Pretest and Posttest Averages

		pre-FCI	post-FCI
No Intervention n=33	Mean	52.93	60.61
	Std. Deviation	20.96	18.66
Intervention Group n=12	Mean	47.50	65.56
	Std. Deviation	21.42	19.29
Total n=45	Mean	51.48	61.93
	Std. Deviation	20.98	18.74

A total of 45 students voluntarily enrolled in Physics 111 lecture and one of three different lab sections designed for engineering majors completed pre and post FCI tests. A group of 12 students participated in our intervention while the remaining 33 did not. Possibly indicative of a self-selection bias where lower performing students were more likely to seek help, the group that did not participate in our intervention did perform slightly better (see Table 1). A Mann-Whitney U test indicated that this difference was not significant, however. Also notable in Table 1 is the finding that the average across all students was below the 60% threshold at pretest, but had improved above that mark at posttest with the intervention group scoring the highest.

Figure 2. Students in the Intervention Group Showed Significantly Greater FCI Gains



All Physics 111 students in the three sections we recruited from improved significantly across the semester, but students who received our intervention showed significantly greater improvement in their FCI scores, $F(1,43)=4.22$, $p<.05$, partial $\eta^2=.09$ (see Figure 2 below). After starting lower than their peers who did not opt to take advantage of our intervention, the intervention students ended the semester with a more accurate Newtonian concept of force. While this understanding of Newtonian mechanics was related to higher grades as end of semester FCI predicted 35% of the variability in final Physics 111 grades, we were somewhat disappointed that students did not, on average, reach the "Newtonian thinkers" threshold of 80%.

In addition to the quantitative analysis of FCI scores described above, students participating in the intervention provided feedback in several qualitative ways. The intervention course was scheduled, twice weekly during evenings, generally concluding at 8:30 pm. On average however, students would typically stay beyond 10:00 pm. The instructor noted that during this extra period of time, students showed further interest in alternative areas of physics, not immediately related to the Physics 111 curriculum, e.g., Cosmology, Relativity, String Theory, Plasma. This is evidence for the development of curiosity within the students. A curious nature is extremely beneficial toward engineering or science related career success.

Facebook was utilized for much of the outreach while recruiting for the course. This social-networking site was also used, by request of the students, to form a group page (ENGR 493-F Physics). Soon after, physics or engineering related content such as videos, jokes and photos were populating the group's page. This is another indication of students' interaction with the desired content.

Responses and comments from the intervention group students highlighted a remarkably positive impact on their attitudes. Rate My Professors.com, is a public website designed for anonymous student ratings of university faculty and courses. Those left by intervention group participants can be viewed by searching for "1074534" on the site's homepage. Comments concerning the physics content were positive, however most were focused more generally. For example, several excerpts from those comments are shown here.

> "…we obtained life lessons about how to succeed in college and professional life, such as time management and organization."
>
> "…to help us open our eyes to life and school and just everything"
>
> "…inspire students to become a better individual in all aspects of life"
>
> "…usually whatever you're hearing is a useful fact about life"

This trend resonated with a majority of intervention group students who continually and specifically requested guidance on leadership skills, organization, time management and personal development. Their interest in developing a more professional skill set is evidence of a heighted desire for success in their chosen engineering career path.

Implications

While further work remains to demonstrate whether this effect generalizes and is replicable, interventions such as those described in this pilot study show promise for moving more students successfully through the Physics 111 gateway toward careers in engineering. It is clear that traditional "chalk-and-talk" approaches do not adequately support many students. From our perspective, the keys to success with these students appear to include a) instructors in lab courses that can connect with students, who are similar enough in background and age that they are able to draw on their own experiences as introductory physics students, b) guided peer interactivity around physics content and focusing on student mental models to identify and correct misconceptions, and c) a broader focus on the whole student including study skills, time management and the development of professional dispositions.

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