Summary of Instructional Redesign Components

Background for Physics 160/161

The Physics 160 series (160 &161) at UNM is our Calculus-based University Physics course taught mostly for students in the physical sciences and engineering. The pre-requisite for the class is college algebra, or a co-requisite of the first semester of calculus. We offer two sections of Physics 160 in the fall, and one in the spring, and two sections of Physics 161 in the spring, and one in the fall. Class sizes are increasing with time, ranging from 80 to 200 depending on the semester. Historically, the DFW rate for these classes depends on the instructor, but the main section of these classes have had a DFW rate approaching 60%. Both courses currently regularly appear in the list of top 20 "Killer Courses" each semester.

The central theme of our effort last year was that students in calculus-based introductory physics will benefit from increased class time with instructors and increased time spent in interactive-engagement activities. The benefit will be in the form of improved learning gains and a reduced failure (DFW) rate.

While there are many different ways to use additional time, Physics Education literature suggests that the only effective reforms are those where part of class-time is spent on small-group interactive-engagement (IE) activities.[1] Accordingly, as increased contact time alone is insufficient, we used this time in proven and innovative ways to increase student learning. Our reform focused on improving students' conceptual understanding.

The biggest logistical and most challenging change of our course-reform plan was the addition of 4 problem-solving sessions in the new studio classroom in Dane Smith Hall. These four sections allowed students to attend required problem solving sessions. In the past, we offered only 1 optional section. As a background to what other institutions do, many highly ranked universities require one hour of problems solving sessions (AKA recitation or discussion sections) to supplement the lecture part of the class including Stanford, Duke, SUNY Stonybrook. For example: Stanford has 14 discussion sections to accompany two lecture sections; Duke has 10 sections of 2-hour recitations to cover two lecture sections; SUNY Stonybrook requires a recitation section along with lectures, etc. Given that each of these schools has a student body with a higher preparation level than that at UNM, it is surprising that our own physics gateway course has only one section of recitation (with a cap of 20) for a lecture class of 180+ students. Our students have less preparation and have less access to resources to bridge their knowledge gap. The Four sections of problems classes (held in Dane Smith Hall in the collaborative class room) allowed us some freedom in testing innovative ideas in physics education pedagogy with the advantage of having control groups.

It has been demonstrated that the greatest difficulty students have with freshman physics is *not* mathematical, but rather conceptual. There are many well known alternative conceptions concerning both physics and mathematical problem solving.[2] As a result, many students do not do well on problems that require organizing and applying concepts; they do succeed at straightforward applications of equations to a "standard" situation. The conceptual difficulties begin immediately.

For this coming year, we intend to keep the extra sessions, but switch from a more conceptual-based group study time to a problem-based group study time. One effective technique for improving student problem solving[3] is to teach students an expert problem-solving strategy, a la Polya.[4] Heller *et al*. developed a physics curriculum around teaching students an expert problem-solving approach called "Cooperative Group Problem Solving. The instructor teaches the problem-solving strategy in class and students practice in the problem solving sessions and on select homework problems. The students are also taught group roles and regularly evaluate the functioning of their group.

References

1 For example, see R.R. Hake, "Active engagement vs. traditional methods: A six thousand student study of mechanics test data for introductory physics courses," *Am. J. Phys*. **66** (1), 64-74 (1998); and E.F. Redish and R.N. Steinberg, "Teaching physics: Figuring out what works," *Physics Today* **52** (1), 24-30 (1999).

2 For example, see http://www.colorado.edu/physics/EducationIssues/cts/index.htm.

3 G. Polya, *How to Solve It* (Doubleday, Garden City NY, 1945).

4 P. Heller, R. Keith, and S. Anderson, "Teaching problem solving through cooperative grouping. Part 1: Group versus individual problem solving," *Am. J. Phys*. **60** (7), 627-636 (1992); and P. Heller and M. Hollabaugh, "Teaching problem solving through cooperative grouping. Part 2: Designing problems and structuring groups," *Am. J. Phys*. **60** (7), 637-644 (1992); and K. Cummings, J. Marx, R. Thornton, and D. Kuhl, "Evaluating innovation in studio physics," *Phys. Ed. Res., Am. J. Phys. Suppl*. **67** (7), S38-S44 July 1999.

Learning/Achievement Gains Assessment

The three main goals of student success for this course reform project for the calculus-based introductory physics sequence (Physics 160 and 161) are as follows:

- Improve student grade achievement and reduce the failure (DFW) rate of these classes
- Improve students' conceptual understanding of the course material
- Improve students' problem solving ability

Improve student grade achievement and reduce the failure (DFW) rate of these classes

Both the large failure rate (failure to get at least a passing grade of "C" or the DFW rate) and the grade distribution in general show an overall low level of achievement in the Physics 160-161 sequence. Comparisons will be made of mid-semester and end-of-semester grade distributions to see if the course modifications are having the desired effect. A successful project outcome would show statistically significant improvement in the student grade distribution and reduction in the DFW rate. A demographic analysis will be done to see the effect on underrepresented minorities in science.

Improve students' conceptual understanding of the course material

One of the issues with current student performance is students having poor basic understanding of key physics concepts both before and after instruction. This issue is well documented in the Physics Education Research Literature that many students get through the introductory physics sequence by memorizing problem solutions rather than by learning physics.[16] One of our project goals is to dramatically improve both students basic understanding of key concepts and their ability to apply conceptual reasoning in problem solving. The former will be evaluated using standard conceptual diagnostics such as the Force Concept Inventory (FCI)[17] and the Brief Assessment of Electricity and Magnetism (BEMA)[18] given at the beginning and end of each semester. The normalized gain from the matched class average pre and post scores will give us an overall figure of merit.[19] The "normalized change" will be used to gauge the improvement of individual students and demographic groups.[20] Students ability to apply conceptual understanding in problem solving will be evaluated by analyzing student exam solutions namely the number of times students applied their conceptual understanding successfully out of the total number of times. A successful project outcome would show statistically significant improvement in both types of measures.

Improve students' problem solving ability

Helping introductory physics students become better physics problem solvers is a major goal of reform efforts nationally for this sequence. To see if the project is successful at helping students become better problem solvers, class performance on exam problems will be compared to a control group, comparing the results of student performance on similar or identical problems to control groups such as class performance in previous terms or to another section taught without the reforms discussed in the previous section. The exam solutions be judged on three criteria: correctness, completeness of reasoning, and students ability to use the strategy taught in the lecture and problem solving sessions. A successful project outcome would show statistically significant improvement in the first two and success for over 50% of students for the latter.

This section needs to be completed.

Re-design expansion plans

The Undergraduate Committee of the Physics and Astronomy department has, for the last several years, been trying to understand the scope and causes of the “killer course” issue in the Physics 160 series. Several aspects have been examined, including the preparation level of the incoming students, and the amount of contact time between the students and faculty. A proposal to change the prerequisite requirements of Physics 160 is currently being considered by the committee, and there has been a long-standing discussion on how to increase the amount of contact time with the students (and the efficacy of that contact time).

Currently, the Physics 160 series generally has one section of problems class offered as an option for students. Historically, around 10-20% of the students enrolled in Physics 160 and 161 were also enrolled in the problems class. It is unclear why there is such a low percentage of students taking the problems class – does only one section not give students sufficient flexibility in their schedule, or do the students just not realize the benefit to themselves of such a class? I believe that the students at this level just don’t have the academic maturity to take a class if it is not required, even though they sorely need it.

Previous recommendations to the committee to increase the number of contact hours has met with little support. The main reason for the lack of support to do this has been the perceived reticence of the College of Engineering to accept an increase in the number of credit hours required of their students. Our department has had several conversations with people from Engineering recently, and while their stance on this issue has become somewhat more flexible, it is not clear if they would accept an increase in the number of credit hours for the course. My plan is to approach the Provost’s office to see if there is a way to convince both Engineering and Physics that the extra credit hour that students would be forced to take if this course reform is made permanent and across all sections is well worth the increase in numbers of STEM students which will make it through the Physics 160 series.

Appendix A

Student learning outcomes (SLOs) for the courses being reformed:

Physics 160: General Physics I (calculus-based introductory physics)

SLO 1: Motion with Constant Acceleration: Students will be able to solve problems involving motion with constant acceleration. Many practical events will be modeled as problems of this type. These include both horizontal motion (for example, an aircraft taking off on the runway, an automobile coming to a stop) and vertical motion near Earth's surface where the acceleration of gravity can be considered constant (for example, a ball thrown straight up in the air). Projectile motion problems also fall into this category; these involve objects experiencing vertical and horizontal motion at the same time (for example, a baseball hit at an angle of 30 degrees above the horizontal).

SLO 2: Newton's Second Law: Students will be able to solve a variety of problems with Newton's second law. This law which deals with forces, inertial mass and acceleration is a foundation of Newtonian Mechanics and has wide application to science and engineering. Problems of various types (possible examples include effects of forces on objects, circular motion, orbits of planets, inclined planes and motion with friction) will be analyzed.

SLO 3: Newton's Universal Law of Gravity: Students will be able to solve problems involving Newton's Universal Law of Gravity. Gravity is one of the 4 fundamental forces in the universe and is therefore one of the most important foundation topics for the future physics and engineers who take this course. Possible examples may include planetary orbits, calculation of the acceleration of gravity on a planet, derivation of Kepler's 3rd law and calculation of forces where masses attract each other.

SLO 4: Conservation of Energy and Momentum: Students will be able to solve problems involving the Conservation of Energy and Momentum. These two laws enable introductory students to solve a wide variety of practical problems. Possible examples of problems include elastic and inelastic collisions and the basic concepts of impulse, momentum, kinetic energy, gravitational potential energy and elastic potential energy.

SLO 5: Rotational Motion: Students will be able to solve problems involving Rotational Motion. Many concepts and their application can be included in rotational motion; possible examples include angular momentum, moment of inertia, conservation of angular momentum, angular velocity, angular acceleration and torque.

These student learning outcomes address the following core competencies:

Addresses UNM/HED Area III Competencies in Physical and Natural Science: 2, 4 & 5.
Addresses UNM/HED Area II Competencies in Mathematics: 1, 2, 3, & 4

These outcomes are measured using results from embedded exam questions and pre/post diagnostics of conceptual understanding

Physics 161: General Physics II (calculus-based)

SLO 1: Electric Force and Field: Student will be able to solve problems involving electric forces and electric fields. Examples would include problems such as calculating forces using Coulomb's Law, using superposition to add forces, using Gauss' Law to solve for electric fields or charge distributions, and interpreting information from sketches of electric field lines.

This student learning outcomes address the following core competencies:

Addresses UNM/HED Area III Competencies in Physical and Natural Science: 3 & 4.
Addresses UNM/HED Area II Competencies in Mathematics: 1, 2, 3, & 4

SLO 2: Magnetic Fields: Students will understand magnitudes and directions of magnetic fields. Examples would include finding the magnitude and direction of a magnetic force on a moving charge or a current carrying wire, recognizing how we know that a current carrying wire produces a magnetic field, calculating the magnetic field due to a current carrying wire, and determining if a particular field would affect a compass.

This student learning outcomes address the following core competencies:

Addresses UNM/HED Area III Competencies in Physical and Natural Science: 1, 4, & 5.
Addresses UNM/HED Area II Competencies in Mathematics: 1, 2, 3, & 4

SLO 3: Ohm's Law and Simple Circuits : Students will be able make calculations involving simple circuits. Examples would include recognizing series and parallel resistors, calculating current, resistance, voltage and power, and showing where a voltmeter or ammeter is connected to a circuit to measure voltage or current.

This student learning outcomes address the following core competencies:

Addresses UNM/HED Area III Competencies in Physical and Natural Science: 2 & 4.
Addresses UNM/HED Area II Competencies in Mathematics: 1, 2, 3, & 4

SLO 4: Faraday's and Lenz' Laws: Students will be able to determine the magnitude and direction of induced currents and voltages. Examples of applications could include generators or transformers.

This student learning outcomes address the following core competencies:

Addresses UNM/HED Area III Competencies in Physical and Natural Science: 2, 4, & 5.
Addresses UNM/HED Area II Competencies in Mathematics: 1, 2, 3, & 4

SLO 5: Thermodynamics: Students will be able to recognize and apply the first and second law of thermodynamics. Examples for the First Law of Thermodynamics would include the connection between heat, work and the conservation of energy, specific heat, phase changes, PV diagrams and thermodynamic graphs, and the determination of the amount of heat and work added to a system for various processes. Examples for entropy and the Second Law of Thermodynamics would include understanding entropy at a conceptual level as disorder, calculating changes in entropy for several processes, recognizing the Second Law of

Thermodynamics in several forms, and stating whether a particular process violates the second law of thermodynamics.

This student learning outcomes address the following core competencies:

Addresses UNM/HED Area III Competencies in Physical and Natural Science: 2, 3, 4, & 5.
Addresses UNM/HED Area II Competencies in Mathematics: 1, 2, 3, & 4

These outcomes are measured using results from embedded exam questions and pre/post diagnostics of conceptual understanding