**STEM Gateway Course Reform Team project information for STEM Gateway website.**
**Please complete this information and return as a Word file to Gary Smith (gsmith@unm.edu)**

**Course Name: General Physics I (calculus-based introductory physics) and General Physics II (calculus-based introductory physics)**

**Course prefix and number: PHYC 160/167 and 161/168**

**Course-reform team members** (Name, title, institution; list team leader first and others alphabetically by last name): Douglas Fields, Associate Professor, UNM; Dinesh Loomba, Associate Professor, UNM; Mary Odom, Full-time Faculty, CNM; Jeff Saul, Lecturer, UNM; James Thomas, Associate Professor, UNM

**Student learning outcomes for the course:**
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

**Short description of how course serves as a gateway to courses in your department and to other majors:**

Physics 160 is a requirement for admissions into all of the Engineering departments (except CS and CM) as well as being the first course required in the series for many science departments.

**Perceptions of reasons for low student achievement of passing grades, rigorous course outcomes, or both:**

Physics 160 is arguably the most difficult class that students in science and engineering need to successfully complete in order to be accepted into their programs. Reasons for low achievement include lack of mathematical preparation, having no physics background, and little preparation for the sheer amount of study work involved in coming to a good understanding of the material.

**Course-reform plan** (a description of the elements of the reformed course: *specific* curricular changes and/or pedagogical changes that will be designed and implemented with an explanation of how each change will address the perceived reasons for past low student achievement)

A central theme of this proposal is 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. The additional contact time, in the form of four special problems class sections, and modification to the lecture part of the course will also allow us to adapt/*develop, implement,* and *assess* research-based approaches to teaching and learning this difficult material.

The biggest challenges students face in introductory physics is that they need to:

- Learn to think in new ways,
- learn new ways to use mathematics by applying it to physical situations,
- learn new ways to solve mathematical problems,
- as well as learn physics concepts

In addition, the standard course design assumes students have prior exposure to physics; although, few of our students do. Thus, our reform will focus on improving students' conceptual understanding, emphasizing visualizing concepts and mathematics,[1] and use of an expert-like problem solving strategy.

The Physics Education literature suggests that the only effective reforms are those where part of class-time in spent on small-group interactive-engagement (IE) activities.[2] Accordingly, as increased contact time alone is insufficient, we plan on using this time in proven and innovative ways to increase student learning. Our reform will include heavy use of proven activities and deployment of activities developed by local physics faculty in both the lecture and the problem solving session with an emphasis on the following:

- Clicker Questions using think-pair-share techniques, i.e. Peer Instruction[3]
- Interactive Lecture Demonstrations[4]
- Cooperative Group Problem Solving[5]
- Supplemental concept and problem solving videos and applets
- Use of warm-up homework assignments to encourage students to read ahead of topic coverage in class.[6]

Four of the 5 types of activities have proven track records for improving learning in introductory physics classes across the country. The use of supplemental videos and applets is a current area of study. Note that these types of small group activities have been shown to benefit underrepresented minority groups in science such as the large Hispanic population in the introductory physics sequence.

The biggest logistical and most challenging change in our course-reform plan will be the addition of 4 problem-solving sessions in the new studio classroom in Dane Smith Hall. These four sections will allow students to attend required problem solving sessions. Currently we offer 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) will allow us some freedom in testing innovative ideas in physics education pedagogy with the advantage of having control groups. We plan to make use of OSET's program to provide undergrad learning assistants to promote active-learning in classes to keep the student-facilitator ratio to 27:1.

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.[7] 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. This is why we intend to emphasize both conceptual understanding, problem solving, and tying them together.

To address students' alternative physics concepts and improve student understanding of key concepts, we will use peer instruction methods on stand-alone clicker questions as well as clicker questions to predict the results of experiments. We will make use of existing libraries of clicker questions for both of these.[8]

One effective technique for improving student problem solving[9] is to teach students an expert problem-solving strategy, a la Polya.[10] Heller *et al*. developed a physics curriculum around teaching students an expert problem-solving approach called "Cooperative Group Problem Solving.[11] 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.

Recently with the rise in interest in the Kahn Academy videos[12] and rise of applets,[13] there has been much discussion of the reverse classroom, where readings and at-home activities replace much of what was done in lecture. We plan to make use of existing materials and make problem-solving videos of key problems in each content area so that students can not only see what was done in example problems but also hear the reasoning behind each step as well as a discussion of how to use diagrams and graphs to visualize the problem and suggest how to go about solving it.

There are several documented cases in the Physics Education Literature where online-homework has been used effectively to encourage students to read up on material before it is covered in class.[14,15] Reading quizzes are replaced by reading homework assignments (warm-ups). This will allow us to lecture less and include more IE activities in class.

So overall, there will be an increased overall emphasis on conceptual understanding, using diagrams and graphs to visualize problem scenarios, and how to use these to be better problem solvers.  These should help improve student learning.  And if student learning and exam performance improve, we expect to see a drop in the DFW rate.

# References


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5 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.

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7 D.P. Maloney, "Research of problem solving: physics," in  *Handbook of Research on Science Teaching and Learning*, edited by D.L. Gabel (Macmillan Publishing Company, New York, 1994), 327-354.

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

[9] See Ref. 7.

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

[11] See Ref. 5.

[12] S. Khan, "Let's use video to reinvent education," TED talk March 2011. Also see http://www.khanacademy.org/ - browse

[13] For example, see W. Christian and M. Belloni, *Physlet Physics: Interactive Illustrations, Explorations, and Problems for Introductory Physics* (Pearson, San Francisco CA, 2004); and http://phet.colorado.edu/en/simulations/category/physics.

[14] G. Novak, A. Gavrin, W. Christian, and E. Patterson, *Just-In-Time Teaching: Blending Active Learning with Web Technology* (B. Cummings, Upper Saddle River NJ, 1999).

[15] See Ref. 6.

[16] See Ref. 3, E.F. Redish, J. M. Saul, and R.N. Steinberg, "Student expectation in physics," *Am. J. Phys.* **66** (3), 212-224 (1998), and P. Murugesan, "Memorize and perish: An underestimated obstacle in introductory physics," *Phys. Teach*. **25** (3), 140 (1987).

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[18] L. Ding, R. Chabay, B. Sherwood, And R.J. Beichner, "Evaluating an electricity and magnetism assessment tool: Brief electricity and magnetism assessment, *Physical Review Special Topics – Physics Education Research* ***2*** (1), 1-7 (2006).

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**Learning/Achievement Gains Assessment** (plan for how the team will assess the impact of reformed-course elements reformed course on student achievement, learning, student satisfaction with their learning and with the course)

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. Both courses currently regularly appear in the list of top 20 “Killer Courses” each semester. 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.

**Timeline:** (An outline of when different course-reform elements and assessments will be implemented during the next year, including the roles of each team member in each implementation step)

Since we submitted the proposal, we have had ongoing electronic discussions and have met at OSET to discuss implementation strategies. We are currently: a) coming to a decision on the format for our problem sessions (a mix of McDermott Tutorials and Problem Solving Strategies); b) reworking the syllabus to include the schedule for problems classes, reading assignments and lecture demonstrations; and c) planning an assessment strategy. Additionally, Fields and Odom will work together to transfer some or all of the clicker questions for use at CNM. Our timeline is:

June 30 - Decide on materials for problem sessions. (All)

June 30 - Finish syllabus. (Fields)

July 31 - Have a clear assessment strategy. (Saul)

July 31 - Have reworks for lectures (improved Clicker Questions and Reading Quizzes). (Fields, Thomas, Loomba)

August 10 - Have materials in hand for problem sessions. (Saul, Fields)

August 15 - All problem session instructors to have been trained in the use of the Tutorials and Problem Solving Strategies. (Fields, Loomba, Saul, Thomas)