

## **DEPARTMENT OF PHYSICS 2013-14 ASSESSMENT REPORT**

### **PHYSICS MAJOR LEARNING OBJECTIVES**

Students graduating with a degree in Physics will be able to:

- A. Understand the fundamental principles of physics and be able to apply these core ideas to analyze physical processes;
- B. Apply quantitative reasoning and critical thinking to solve complex problems, both theoretical and experimental in nature;
- C. Independently learn new technical subjects and skills;
- D. Design and assemble experiments, quantitatively analyze the results using appropriate statistical procedures and tests of systematic errors, and draw meaningful conclusions;
- E. Effectively communicate scientific ideas, both theoretical and experimental, to diverse audiences through written and oral presentations, both formal and informal;
- F. Work effectively and inclusively as a member of diverse collaborations to solve problems.

### **RESULTS**

#### **Pre- and post-instruction tests/surveys: (SLOs: A,B,C)**

These exams give us a snapshot of the students' working knowledge in physics, conceptual understanding, and ability to efficiently solve problems. These exams are a core part of our assessment of our first three SLOs. Since the tests are nationally normed they enable us to make quantitative comparisons of our students' performance to that of students from other institutions.

A subset of the exams are given before and after instruction (at the beginning of the course and at the conclusion of the course) to provide a quantitative measure of student improvement during the course. The gain is calculated as the difference between pre- and post-instruction scores divided by the number of incorrect answers on the pre-test.

#### **1. Physics 1001 (Force Concept Inventory, FCI, a nationally normed assessment tool)**

The Force Concept Inventory (FCI) instrument is designed to assess student understanding of the most basic concepts in Newtonian physics. This forced-choice instrument has 30 questions and looks at six areas of understanding: kinematics, Newton's First, Second, and Third Laws, the superposition principle, and types of forces (such as gravitation, friction). Each question offers only one correct Newtonian solution, with common-sense distractors (incorrect possible answers) that are based upon student's misconceptions about that topic, gained from interviews.

	2013	2012	2011
Gain between post- and pre-test:	27	30	31
Overall post-test score:	47	52	48

Studies have shown that in a traditional, well-taught lecture class, the FCI gain is measured to be around 20% while in a class employing a wide range of active engagement and peer-to-peer instruction techniques, the FCI gain can approach close to 50%.

For the overall post-test FCI score, the generally acknowledged threshold for understanding the material is an average of about 60%.

## **2. Physics 1003 (Brief E&M Assessment, BEMA, a nationally normed assessment tool)**

The Brief Electricity and Magnetism Assessment (BEMA) attempts to assess what students know about the most basic and central concepts of the calculus-based introductory E&M course. It is comprehensive, covering topics from the Coulomb force law to magnetic induction, but omitting radiation because it is very common for the introductory course not to get that far. It has been used by various instructors in various settings and has been judged an appropriate and fair assessment of introductory E&M by physicists experienced in teaching E&M at various levels. It is not aimed at any particular curriculum but contains only those elements common to all calculus-based introductory courses.

	2013	2012
Gain between post- and pre-test:	14	29
Overall post-test score:	37	47

Studies have shown that in a traditional, well-taught lecture class, the BEMA gain is measured to be around 20% while in a class employing a wide range of active engagement and peer-to-peer instruction techniques, the gain can be above 30%.

For the overall post-test BEMA score, the generally acknowledged threshold for understanding the material is an average of about 60%.

## **3. Physics 2004 (Physics GRE-based assessment, Physics GRE-9277, nationally normed for students applying to graduate school)**

The Physics Graduate Record Exam (GRE) test consists of approximately 100 five-choice questions, some of which are grouped in sets and based on such materials as diagrams, graphs, experimental data and descriptions of physical situations. The aim of the test is to determine the extent of the examinees' grasp of fundamental principles and their ability to apply these principles in the solution of problems.

Most test questions can be answered on the basis of a mastery of the first three years of undergraduate physics.

In Physics 2004, we use a subset of questions from the GRE test centered around topics that students should have familiarity with through the General Physics sequence (including Modern Physics, PHYS 2004).

2013 class average = 21% (percentile based on students applying for graduate study = 28th)

Subject area breakdown:

Subject	2013 results	2012 results
Classical mechanics:	25	N/A
Electromagnetism:	18	N/A
Optics:	25	N/A
Thermodynamics:	19	N/A
Quantum:	18	N/A
Special relativity:	22	N/A
Laboratory methods:	19	N/A
Special topics:	38	N/A

**4. Physics 4950 (Physics GRE-0177, nationally normed for students applying to graduate school)**

The Physics Graduate Record Exam (GRE) test consists of approximately 100 five-choice questions, some of which are grouped in sets and based on such materials as diagrams, graphs, experimental data and descriptions of physical situations. The aim of the test is to determine the extent of the examinees' grasp of fundamental principles and their ability to apply these principles in the solution of problems. Most test questions can be answered on the basis of a mastery of the first three years of undergraduate physics.

In Physics 4950, our Capstone class, we use a complete GRE test covering all subjects in Physics.

Subject area breakdown:

Subject	2014 results	2013 results	National average
Classical mechanics:	20	24	51.6
Electromagnetism:	21	27	48.2
Optics:	15	20	39.8
Thermodynamics:	15	21	51.9
Quantum:	25	11	45.4
Atomic:	29	29	52.1
Special relativity:	0	9	38.8
Laboratory methods:	33	39	38.5
Special topics:	20	20	38.8

**Comparison of Physics 2004 (2<sup>nd</sup> year) to Physics 4950 (4<sup>th</sup> year) results:**

Subject	Physics 2004	Physics 4950 (2-yr avg)
Classical mechanics:	25	22
Electromagnetism:	18	24
Optics:	25	18
Thermodynamics:	19	18
Quantum:	18	18
Special relativity:	22	5
Laboratory methods:	19	36
Special topics:	38	20

**Summary of assessment results from nationally normed exams:**

A Department goal is for our students to achieve the national average on all nationally normed exams. (This goal, in the case of the GRE exam, may be aspirational as we are comparing all our students to a subset of students who applied to graduate school in Physics.)

The sobering results of our assessments are that we are consistently falling short of our goals for our students. There is a persistent 10+ point gap between the overall class performance on the FCI in Physics 1001 and the acknowledged level for “understanding.” The gap between our students’ performance on the BEMA and the level for understanding in Physics 1003 is around 20 points. To our faculty’s and students’ credit, the improvement in performance in our General Physics courses is at or above the baseline for traditional instruction.

In both Physics 2004 and Physics 4950, the performance of our students falls short of our goals, and in fact the performance of the 4<sup>th</sup>-year students in Physics 4950 shows little improvement compared to the 2<sup>nd</sup>-year students in Physics 2004. On the other hand, one should be careful about reading too much into the results as relatively few students (< 10) have taken the exams each year.

The Department held a meeting of the tenure-track faculty on 10 September 2014 to “close the loop” and strategize on what improvements might be made to curriculum and teaching methods.

It was the opinion of the faculty that based on these results, the students overall were suffering from a lack of a fund of knowledge about physics and had significant weaknesses in conceptual understanding and problem solving skills that needed to be addressed.

The following plans were adopted:

(1) Basic physics knowledge taught in the General Physics sequence (PHYS 1001-1003, PHYS 2004) would now be emphasized throughout the upper-division curriculum by additional “basic” problems added on to homework assignments to give students extra practice at the basic concepts. This could be done without sacrificing the advanced instruction that is part of the present curriculum.

(2) We will no longer allow note sheets on upper division exams to further emphasize learning and remembering physics concepts, relations, and problem solving strategies to improve students' fund of physics knowledge.

(3) We will increase use of oral exams and in-class presentations of problem solutions, and peer-to-peer learning strategies, to further emphasize and practice accessing the fund of physics knowledge.

(4) We will continually emphasize throughout lower and upper division the "Prepare-Solve-Assess" strategy of problem solving.

(5) We will expand use of peer evaluation to help teach students how to evaluate their own work.

(6) In future years, the FCI and BEMA will be analyzed by subject area to specifically target what areas of instruction need most improvement.

**Problem Sets and In-class Problems (individual & group, rubric-based assessment): (SLOs: A,B,C,E,F)**

A core part of the Physics curriculum is learning to apply the concepts of physics to solve complex problems and present the solutions in written form, and sometimes in oral presentations. The problems are solved both individually and in groups. This core part of the curriculum, related to five out of our six SLOs, is evaluated with the following rubric.

Each problem is graded out of 5 points according to:

- 5** The student clearly understands how to solve the problem. Minor mistakes and careless errors can appear insofar as they do not indicate a conceptual misunderstanding.
- 4** The student understands the main concepts and problem-solving techniques, but has some minor yet non-trivial gaps in their reasoning.
- 3** The student has partially understood the problem. The student is not completely lost, but requires tutoring in some of the basic concepts. The student may have started out correctly, but gone on a tangent or not finished the problem.
- 2** The student has a poor understanding of the problem. The student may have gone in a not-entirely-wrong but unproductive direction, or attempted to solve the problem using pattern matching or by rote.
- 1** The student did not understand the problem. They may have written some appropriate formulas or diagrams, but nothing further. Or, they may have done something entirely wrong.
- 0** The student wrote nothing or almost nothing.

**The Department goal is for students to achieve an average of 4.0 or better.**

## 1. Physics 2004

The fourth problem set of Modern Physics was assessed, with the following results:

**2014 overall performance: 3.8/5.0**, which is close to our goal of 4.0, which means that the students understand the main concepts and problem-solving techniques (but still have some non-trivial gaps in reasoning).

**Problem 1: 3.0/5.0** (On relativistic energy, most students understood but a few were confused.)

**Problem 2: 4.0/5.0** (On four-vectors, all students scored  $> 3$  and demonstrated basic understanding.)

**Problem 3: 4.6/5.0** (On mass-energy relation, all students scored  $> 3$  and demonstrated basic understanding.)

**Problem 4: 3.4/5.0** (On relativistic acceleration, velocity addition – rocket problem – most students understood but a few were confused.)

## 2. Physics 3302

The first problem set of Quantum Mechanics II was assessed, with the following results:

**2014 overall performance: 3.5/5.0**, which equates to somewhere between partial and general understanding of how to solve the problems. This falls short of our goal, but the students definitely show promise working on long-form, complex solutions.

**Problem 1: 4.2/5.0** (This was a fairly complex tutorial on Bell's inequality and entanglement, and everyone scored  $> 3$ , demonstrating basic understanding.)

**Problem 2: 3.2/5.0** (On time-dependence of quantum states, coupled vs. uncoupled angular momentum – involved combining two concepts and caused some confusion.)

**Problem 3: 3.5/5.0** (On addition of angular momentum, some confusion over magnitude vs. projection.)

**Problem 4: 3.8/5.0** (Conversion between coupled and uncoupled angular momentum bases, expectation values. Generally good understanding.)

**Problem 5: 2.9/5.0** (Addition of 3 spins. Extension of ideas from class, most people had right ideas but struggled to carefully carry out the multi-step solution.)

### **3. Physics 4002**

*Course not taught in 2014.*

#### **Summary of assessment results from problem set rubrics:**

Lower division students in PHYS 2004 and upper division students in PHYS 3302 performed reasonably well on the long-form problem sets, close to our Department goal of a 4.0/5.0 average. Extra effort needs to be placed on presentation and complex critical reasoning to work through problems to their conclusion. This has been a point of emphasis for the Department, and there is significant peer-to-peer interaction and learning in the solving of problems.

Increased emphasis throughout lower and upper division courses on the “Prepare-Solve-Assess” strategy of problem solving should serve to improve the problem solving and presentation skills. Also the increased use of peer evaluation and oral presentations should further enhance student performance on problem sets.

In the 2014-2015 academic year, we plan to use a problem set from Physics 2004 to conduct a norming session where all the tenure-track faculty will evaluate the same problem sets using the rubric to determine consistency.

#### **Experiment with Presentation, Lab Notebook write-up (rubric-based): (SLOs: A,B,C,D,E,F)**

Another core part of the Physics curriculum is learning to apply the concepts of physics to carry out laboratory experiments, analyze data, and present the conclusions in written form and in oral presentations. The experiments are carried out in teams. Laboratory work, a point of emphasis for the Department, is related to all six of our SLOs, and is of central importance to developing practical skills of interest in graduate school and industry.

We employ a similar experiment, scaffolded in difficulty, at three different levels: Physics 1001 (the first course for majors), Physics 2004 (the 2<sup>nd</sup> year level course), and Physics 3281/3283 a 3<sup>rd</sup>/4<sup>th</sup> year course. The goal of the experiment is to measure the acceleration due to gravity, and students are given increasing levels of independence and less guidance from faculty as their experimental skills increase.

A variety of aspects of experimental work are assessed on a scale of 0-5 using the following rubric:

5 = Complete, independent mastery;

4 = Solid performance but with minor misunderstandings, needed some guidance;

3 = Grasped basic idea and mostly understood but made some significant errors, needed significant guidance;

2 = Poor understanding, made many errors;

1 = Did not demonstrate competence;

0 = No effort in this area.

### 1. Physics 1001

*Not conducted in 2013.*

### 2. Physics 2004

**Laboratory Notebook and Class Presentation (goal is an average of 4.0 or above in each area):**

Evaluation area	2014 results	2013 results
Understanding of physics principles:	3.5	N/A
Experimental design/procedure:	3.0	N/A
Quantitative reasoning, data analysis:	2.6	N/A
Critical thinking, systematic errors:	1.9	N/A
Effective communication:	3.6	N/A
Inclusive collaboration:	4.5	N/A
Draws meaningful conclusion:	2.3	N/A

### 3. Physics 3281/3283

**Laboratory Notebook and Class Presentation (goal is an average of 4.5 or above in each area):**

Evaluation area	2014 results	2013 results
Understanding of physics principles:		3.9
Experimental design/procedure:		4.3
Quantitative reasoning, data analysis:		3.7
Critical thinking, systematic errors:		3.9
Effective communication:		4.7
Inclusive collaboration:		4.5
Draws meaningful conclusion:		4.3



**Comparison between levels:**

**Laboratory Notebook and Class Presentation (goal is an average of 4.5 or above in each area):**

Evaluation area	PHYS 1001	PHYS 2004	PHYS 3281/3
Understanding of physics principles:	N/A	3.5	3.9
Experimental design/procedure:	N/A	3.0	4.3
Quantitative reasoning, data analysis:	N/A	2.6	3.7
Critical thinking, systematic errors:	N/A	1.9	3.9
Effective communication:	N/A	3.6	4.7
Inclusive collaboration:	N/A	4.5	4.5
Draws meaningful conclusion:	N/A	2.3	4.3

The assessment indicates that in the area of experimental techniques, laboratory notebook write-up, group collaboration, critical thinking and data analysis, and presentation our students are significantly improving in all areas from Physics 2004 to Physics 3281/3283. Students are reasonably close to meeting our goals for all SLOs according to this assessment by their 3<sup>rd</sup>/4<sup>th</sup> year.

(This is supported by the strong performance by students on the GRE exams in the area of laboratory procedures.)

All areas where students are below target relate to the students' deeper understanding of the physics involved in the experiments, a weakness reflected in part on the students' performance on the Capstone GTE Exam (PHYS 4950) assessment. This again indicates further work is required to help our students meet SLOs A, B, and C.

## SUMMARY

During the 2012-13 academic year the Physics Department developed new Physics Major/Minor SLOs, a new Assessment Plan, and a Curriculum Map. In 2013-14 the Department refined these assessment tools. These efforts were essential in clarifying what we expect of our students and what the focus of our curriculum should be. Our Assessment Plan was only partially implemented in 2012-13, and in 2013-14 we have nearly fully implemented the plan. In 2014-15 we plan to complete implementation of our Assessment Plan, which will provide annual assessment of all our SLOs.

Based on our 2013 Department Assessment and Curriculum Meeting we:

- (1) Modified Physics Major SLOs (E) and (F) to include consideration of diversity.
- (2) Revised the laboratory rubric for assessment of Physics 1001, 2004, and 3281/3 laboratory experiences.

Our overall assessment of the Physics curriculum is that our students appear to be achieving success in meeting SLOs (D), (E), and (F), while they are falling short of our Department's goals for their performance related to SLOs (A), (B), and (C).

During our 2014 Department Assessment and Curriculum Meeting, we identified several areas to focus on with regards to SLOs and assessment during the 2014-15 academic year.

It was the opinion of the faculty that based on these assessment results, the students overall were suffering from a lack of a fund of knowledge about physics and had significant weaknesses in conceptual understanding and problem solving skills that needed to be addressed.

The following plans were adopted:

- (1) Basic physics knowledge taught in the General Physics sequence (PHYS 1001-1003, PHYS 2004) would now be emphasized throughout the upper-division curriculum by additional "basic" problems added on to homework assignments to give students extra practice at the basic concepts. This could be done without sacrificing the advanced instruction that is part of the present curriculum.
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- (4) We will continually emphasize throughout lower and upper division the "Prepare-Solve-Assess" strategy of problem solving.
- (5) We will expand use of peer evaluation to help teach students how to evaluate their own work.

(6) In future years, the FCI and BEMA will be analyzed by subject area to specifically target what areas of instruction need most improvement.

(7) We will analyze the utility of problem set solutions using BlackBoard analytics.

(8) We will develop assessment strategies for our Physics 2700 series and for our GE course offerings.