Department of Physics and Astronomy Self-Study Executive Summary

The learning goals for physics majors at Millikin University are:

1. Students will solve complex problems that require integrating knowledge from a variety of subfields, including classical mechanics, classical electrodynamics, thermodynamics, atomic and nuclear physics, and quantum mechanics, as well as incorporating sophisticated mathematical techniques such as partial differential equations, tensor mathematics, calculus of vector fields, and linear algebra.

2. Students will follow the scientific method to design and carry out informative and professionally interesting experiments, utilizing laboratory techniques sufficiently advanced as to allow an easy transition to graduate school or industry.

3. Students will effectively communicate scientific knowledge to general audiences as well as colleagues in the field via oral presentations, formal journal articles, and writing for the layperson.

To measure student learning with respect to these goals, the department assesses students at during all four years of their time at Millikin, using feedback from assessments at each level to guide improvement. Assessment methods involve a test which can be compared against national baselines, a test developed by the Educational Testing Service and given to physics majors across the country, and departmentally-developed rubrics assessing the ability of students to design and carry out research projects and to communicate the results of that research both orally and in writing. For the 2005-2006 AY, the department rates student learning in each of these areas as somewhere between yellow and green. However, the rubrics which have been developed to test goals two and three are new as of this summer, and have yet to be tested.

The physics department will be undergoing a significant change (with great hopes for the future) with the addition of a second full-time faculty member. It is expected that the rebalancing of departmental workloads, along with the insights and influence of another expert in the field, will produce further advances in student learning. The 2006-2007 AY self-study should show this influence, along with more quantitative results regarding student learning as a result of the development of new assessment rubrics.

Respectfully submitted by Eric Martell, on 6/18/06.

Department of Physics and Astronomy Self-Study

I. Goals

In the opinion of the Department of Physics and Astronomy, upon the completion of a physics major at Millikin University, a student should be able to:

4. Solve complex problems that require integrating knowledge from a variety of subfields, including classical mechanics, classical electrodynamics, thermodynamics, atomic and nuclear physics, and quantum mechanics, as well as incorporating sophisticated mathematical techniques such as partial differential equations, tensor mathematics, calculus of vector fields, and linear algebra.

5. Follow the scientific method to design and carry out informative and professionally interesting experiments, utilizing laboratory techniques sufficiently advanced as to allow an easy transition to graduate school or industry.

6. Effectively communicate scientific knowledge to general audiences as well as colleagues in the field via oral presentations, formal journal articles, and writing for the layperson.

A student who is able to reach these goals successfully will also be satisfying the core goals expressed in the mission statement for Millikin University. All of the departmental goals will help a student achieve *professional success*, as they are fundamental to the success of any physicist. Meeting all three goals will also contribute to a Millikin graduate being able to be a *citizen in a global environment*. Dealing with problems in a global society requires integration of knowledge and strong problem solving skills. Performing informative and interesting experiments is one way a physicist connects with the world, advancing the basic principles of both pure and applied science. Finally, a good physicist must communicate not only what they have done, but why it is important, and communicate these things not just to their colleagues, but to the world at large. A successful Millikin graduate in Physics will also be *prepared for a personal life of meaning and value*. This goal is primarily fulfilled by the first and third departmental goal, although depending on the individual, all three goals pertain to it. Being able to solve problems in one's personal life, whether at work or at home or in the community is a necessary skill to be able to grow and move past challenges. Also, being able to effectively communicate what they know and why it's important to them will help students reach personal goals throughout their lives.

II. Snapshot

The Department of Physics and Astronomy at Millikin University was staffed for the 2005-2006 AY by one full-time Assistant Professor, Eric Martell, and one half-time Assistant Professor, Zhijun Wang, who held a shared appointment with Computer Science. A search has been recently completed to expand the department to two full-time faculty, both tenure-track. It is expected that this new hire, Casey Watson, will greatly assist in the teaching of students and the management/development of programs, although staffing is still below what would be optimal. Both faculty will carry overloads for each semester in 2006 and beyond. The department is housed in the Leighty-Tabor Science Center (LTSC), which opened in 2002, and provides an adequate facility for the teaching of physics. Some of the space originally assigned to the department has been transferred to the School of Nursing, and additional space will be renovated this summer in order to facilitate the reaching of departmental goals. The department is also in the process of submitting a grant proposal designed to upgrade laboratory equipment to better fit with modern pedagogical techniques.

The number of students who are physics majors has grown significantly over the past two years. As of Fall 2004, there was one sophomore and three freshmen physics majors. By Fall 2005, there were two juniors, three sophomores, and seven freshmen, as well as one junior physics minor. As for Fall 2006, we expect to have two seniors, three juniors, five sophomores, and six freshmen, as well as two minors.

Most students who pass through courses in Physics or Astronomy are not Physics majors, and therefore serve as evidence for the department's extensive service to the University. In addition, because of the excellent astronomical equipment that the University has, the department serves the community by offering regular public viewings at the Requarth Observatory, as well as numerous public lectures to local groups, such as grade school, middle school, and high school students, Boy Scout troops, Girl Scout troops, and professionals from the Decatur area.

During the past year, the department revised the curriculum as well as the requirements for completion of the major. The revisions reflect the best practices in the field as well as the expertise and abilities of the faculty in the department. There is a curriculum map in Appendix I detailing how the revised curriculum matches up with departmental learning goals.

III. <u>Learning Story</u>

The typical Physics major at Millikin will take PY 151 and 152 during their freshman year. (Some students will have Advanced Placement credit that will allow them to skip one or both of these classes.) These courses comprise a fairly standard year-long introduction to Physics, and have MA 140 and 240, Calculus I and II, as co-requisites since the primary language of doing Physics is Calculus. These courses involve both lecture and laboratory, and heavily integrate modern pedagogy, specifically active learning, peer instruction, and inquiry-based methods. (These methods will also be a strong component of the instruction in PY 100 and 101, and PY 111 and 112, which primarily serve non-majors.) As sophomores, Physics majors would take PY 253, an introduction to Modern (20^{th}-century) Physics, and PY 262, Experimental Physics I (focusing on Electronics). These courses are where students will first experience substantive experimental design, and will also involve instruction in writing of scientific papers. The courses will culminate in seminar-style presentations that will be open to other physics majors, minors, and faculty. Similar presentations will occur at the end of the junior and senior years, at the end of which students will present work from a senior research project. In Modern Physics, students will also be introduced to Mathematica™, the most extremely popular and powerful computational and analysis software package.

During their junior and senior years, a typical physics major will take an assortment of standard courses, including Theoretical and Applied Mechanics, Electromagnetism, Physical Chemistry, and Quantum Mechanics. Along with these courses will be a number of math and other science classes, depending on student interest and career goals. These courses are primarily theory-based, and will involve extensive integration of material from a variety of classes and fields. However, during the junior year, students will take a more advanced experimental research class (Experimental Physics II - PY 362), which will introduce them to National Instruments LabView™, the industry and academic standard in experimental control and data acquisition. As seniors they will complete an extensive individual research project, to act as a capstone experience.

A key component of the Physics program at Millikin is that each student will design their own major, in consultation with their advisor and any other relevant faculty. This will allow for greater flexibility in the curriculum, which experience shows is highly desirable to many students. Because of the flexibility in the program, advising is especially important. Since each student's interests and goals influence what classes they take and what path they take through Millikin, a process of regular reflection on what he or she has done and want to do is necessary to make the courses fit specific needs. The department has designed documents to help students through this process, which, since the department is small, will be reviewed regularly in meetings with the student and their advisor to make sure that each student is on the right track. The primary goals for each student are to be able to graduate in a timely manner with courses which reflect that student's interests and needs and to be able to pursue whatever course they are interested in post-graduation, such as graduate school, industry, or other professional school.

IV. <u>Methods</u>

The goals described in section I will be met in many different courses, which are listed in the curriculum map attached in the appendix. For the purposes of this study, assessment and data collection will take place in the following courses:

Goal 1: Progress towards goal 1 will be measured in two ways:

1) Students in PY 151 will take the Force Concept Inventory as a pre-test and post-test. The FCI is a test containing 30 questions on Newtonian mechanics and is nationally used as a benchmark for student learning in first semester introductory physics classes. The results are reported as average percent gain, (Post Test – Pre Test)/(30 – Pre Test)*100. This allows us to compare the improvement of students who begin the course with different backgrounds. Data has been collected from thousands of classes at dozens of universities over the last decade, and results for different pedagogical methods are well known. Courses utilizing primarily traditional, lecture-based pedagogies average a 23% gain, while courses utilizing primarily active learning methods average a 48% gain.

The department goals for the FCI are as follows: Green ≥ 40%, Yellow ≥ 30%.

2) PY majors, at the end of their sophomore, junior, and senior years, will take the Physics Major Field Test, administered by the Educational Testing Service. The

MFTs were introduced in 1989, and are given, in a variety of disciplines, at over 700 colleges and universities (including the MU Chemistry department). The scores will be tracked over the (up to) three years that students take the exam, and progress will be measured both on how individual students improve as well as how MU students compare to national results. There are three scores reported by ETS – a Scaled Score, ranging between 120 and 200 (2004 median score for seniors – 144), an Introductory Physics Score, ranging between 20 and 100 (2004 median score for seniors – 44), and an Advanced Physics Score, ranging between 20 and 100 (2004 median score for seniors – 46).

It is expected that students will improve as they progress through Millikin, so that a satisfactory result for a sophomore would be lower than that for a junior, etc. The departmental goals for each of the three courses are listed below (in terms of average percentile ranking for the overall scaled score):

- **Soph.** Green: Percentile ranking ≥ 25 Yellow: Percentile ranking ≥ 10
- **Junior** Green: Percentile ranking ≥ 45 Yellow: Percentile ranking ≥ 30
- **Senior** Green: Percentile ranking ≥ 60 Yellow: Percentile ranking ≥ 50

Goals 2 and 3 will be evaluated through the rubrics discussed below. Because for the 2005-2006 AY, there were no senior physics majors and one only junior physics major, the scheduled evaluations were scheduled to take place at the sophomore level or below in an attempt to provide sufficient data to make the evaluations worthwhile (see data and improvement plans for a further discussion of this topic).

We have developed a rubric (to be used beginning in 2006-2007) which will produce numerical results that can be used to assess learning, but the core of the evaluation process will be the discussion between the student researcher, faculty, and other students. In the future, we expect to be able to analyze student research and presentations in sophomore, junior, and senior courses. This will allow for a three-year process whereby students can reflect on their work and use the evaluations to improve their presentations and experimental design each year.

Goal 2: Students in PY 253, PY 362, and PY 481/482 will design experiments that (in PY 253 and 362, and perhaps 481/482) have known results so that the experimental design can be checked for errors. Students may also present their experimental designs to faculty and other students who will review their procedure. The criteria for evaluation are spelled out in the table below.

Item	Criteria		
	Excellent	Adequate	Unsatisfactory
Background Research	**[5 points]** A thorough explanation and analysis of previous work, development of appropriate and insightful study questions and hypotheses, synthesis into a coherent proposal.	**[3 points]** Shows some evidence of the process but fails to meet a significant amount of criteria for excellence.	**[1 point]** Restates some general ideas or issues but shows no evidence of analysis or understanding of what has come before.
Research Design	**[5 points]** Reasonable, efficient, and practical approach to acquiring results. Research doable in time available and with resources available. Uses scientific method and results address study questions and hypotheses. External influences well-controlled or understood.	**[3 points]** Shows some evidence of effective research plan, but fails to meet a significant amount of criteria for excellence.	**[1 point]** Design fails to test hypotheses, is undoable given available resources, controls not well-understood.
Data Analysis	**[5 points]** Results well-understood and appropriate and justifiable conclusions drawn from data or calculations. Thorough systematic and statistical error analyses. Honest comparison with previous results influences discussion of results and conjectures about future work.	**[3 points]** Shows some evidence of understanding of results and errors in context of prior results, but fails to meet a significant amount of criteria for excellence.	**[1 point]** Results clearly not well-understood, incomplete analysis, missing or inadequate error analysis, failure to compare with previous results.

It is expected that students will improve as they progress through courses, so that a satisfactory result for a student in PY 253 would be lower than that for a student in PY 362, etc. The departmental goals for each of the three courses are listed below:

- **PY 253** Green: Course avg. ≥ 8 Yellow: Course avg. ≥ 6
- **PY 362** Green: Course avg. ≥ 10 (with no 1's) Yellow: Course avg. ≥ 8
- **PY 481/2** Green: Course avg. ≥ 12 (with one 5) Yellow: Course avg. ≥ 10 (with no 1's)

Goal 3: Students in PY 253, PY 362, and PY 481/482 will present their results in written and oral form to an open audience of faculty and other students. The criteria for evaluation are spelled out in the tables below.

Oral Presentations:

	Excellent	Adequate	Nominal
Clarity of Presentation	**[3 points]** Clear logic and structure of presentation. Good ability to project voice and make eye contact. Strong command of language and grammar. Clear confidence in command of material.	**[2 points]** Reasonably clear overall, but fails to meet a significant amount of criteria for excellence.	**[1 point]** Poorly organized presentation – no clear structure or logic. Unclear speaking voice, little or no eye contact.
Length	**[3 points]** Length of presentation appropriate for forum. Included enough material to keep presentation consistently strong, but not too dense. No filler.	**[2 points]** Presentation a little too long or too short, but otherwise lacking filler and not too dense.	**[1 point]** Significantly too much or too little material of substance.
Quality of slides	**[3 points]** Slides easy to read. Good contrast between text and background. Interesting choices for graphics and/or multimedia. Slides not too crowded or sparse.	**[2 points]** Lacking noticeable qualities of excellence, but overall slides are reasonably constructed.	**[1 point]** Poor construction of slides. Difficult to read, low contrast, graphics clumsy or distracting.
Demonstration of understanding of physics	**[3 points]** Clear understanding of subject and definitions of presentation-specific terms. Insight into material beyond what's written on slides. Audience questions answered in a way to illustrate a complete knowledge of the topic.	**[2 points]** Shows some command of material and can answer some questions, but fails to meet a significant amount of criteria for excellence.	**[1 point]** Understanding of material clearly lacking. Unable to answer audience questions. Does not understand basic definitions of terms used. No insight.
Appropriateness of presentation	**[3 points]** Presentation aimed at appropriate audience – professional, classmates, general audience, etc. Defined terms at appropriate level of depth and complexity. Subtleties included only when necessary. Humor, etc, takes into account audience level and composition.	**[2 points]** Generally appropriate talk, but at times talking above or below heads of audience. Failed to define some necessary terms. Some remarks perhaps inappropriate for audience.	**[1 point]** Failed to take audience into account when presenting.

It is expected that students will improve as they progress through courses, so that a satisfactory result for a student in PY 253 would be lower than that for a student in PY 362, etc. The departmental goals for each of the three courses are listed below:

- **PY 253** Green: Course avg. ≥ 8 Yellow: Course avg. ≥ 6
- **PY 362** Green: Course avg. ≥ 10 Yellow: Course avg. ≥ 8
- **PY 481/2** Green: Course avg. ≥ 12 (with no 1's) Yellow: Course avg. ≥ 10

Written Presentations:

	Excellent	Adequate	Nominal
Clarity of Writing	**[5 points]** Clear logic and structure of paper. Strong command of language, spelling, and grammar. Clear confidence in command of material. Easy to read.	**[3 points]** Overall, a solid paper, but fails to meet a significant amount of criteria for excellence. Could use proofreading.	**[1 point]** Poorly organized paper – no clear structure or logic. Poor grammar or spelling. Difficult to understand and read.
Length and Appropriateness of paper	**[5 points]** Length of paper appropriate for forum or meets assigned criteria. Included enough material to keep paper consistently strong, but not too dense. No filler. Paper aimed at appropriate audience – professional, classmates, general audience, etc. Humor, etc, takes into account audience level and composition.	**[3 points]** Paper a little too long or too short, but otherwise lacking filler and not too dense. Generally appropriate level of writing, but at times above or below heads of audience. Some remarks perhaps inappropriate for audience.	**[1 point]** Significantly too much or too little material of substance. Failed to take audience into account when writing.
Demonstration of understanding of physics	**[5 points]** Clear understanding of subject and definitions of presentation-specific terms. Insight into material beyond what's found in references. Defined terms at appropriate level of depth and complexity. Subtleties included only when necessary.	**[3 points]** Shows some command of material and understanding of material obtained from references. Failed to define some necessary terms. Failed to meet a significant amount of criteria for excellence.	**[1 point]** Understanding of material clearly lacking. Does not understand basic definitions of terms used. No insight.

It is expected that students will improve as they progress through courses, so that a satisfactory result for a student in PY 253 would be lower than that for a student in PY 362, etc. The departmental goals for each of the three courses are listed below:

- **PY 253** Green: Course avg. ≥ 8 Yellow: Course avg. ≥ 6
- **PY 362** Green: Course avg. ≥ 10 Yellow: Course avg. ≥ 8
- **PY 481/2** Green: Course avg. ≥ 12 (with no 1's) Yellow: Course avg. ≥ 10

V. <u>Data</u>

For goal 1, the FCI was administered during Fall 2005 to PY 225 (the equivalent to PY 151). Forty-one students took both the pre-test and the post-test. The average pre-test score was 9.0 (down from 9.4 in 2004), the average post-test score was 16.3 (down from 17.0 in 2004), resulting in an average percent gain of 34.7% (down from 36.9% in 2004).

The Physics MFT was administered at the end of the Spring 2006 semester to five physics majors, three sophomores and two juniors. The average scaled score was 135.5 for sophomores and 138.5 for juniors. The average introductory physics score was 35.8 for sophomores and 36 for juniors. The average advanced physics score was 36.3 for sophomores and 41.5 for juniors. Since this was the first year that the MFT was offered, there is no data for previous years.

There is no analyzable data for either goal 2 or goal 3. The above rubrics were developed after an attempt at a purely qualitative study of materials failed to produce somewhat objective results which could be communicated easily to others.

VI. Analysis

Goal 1 – Yellow Light (verging on Green)

FCI: At least at the introductory level, testing indicates that we are approaching a high level of success, compared with other programs. Millikin students test higher than the majority of physics students nationally when it comes to learning conceptual material in introductory physics, indicating that the methodology being used is fairly successful. However, data indicates that continued revision of pedagogy and incorporation of new techniques into instruction should allow us to improve on our current results. The decrease from 2004 is statistically insignificant, and is most likely from a not-entirely-successful incorporation of new pedagogy into the course. Results from student surveys suggest that some techniques which are reported to be highly successful elsewhere have not been well-received at Millikin. Research is regularly published which tracks performance on the FCI, and so we should be able to keep comparing our results with evolving national standards.

MFT: Since the number of students who are taking these exams is small, we have to be careful about any conclusions that we draw from the data. The percentile rankings for the sophomores were 25% for the overall score, 30% for introductory physics, and 25% for advanced physics. For the juniors, the rankings were 30%, 25%, and 35%. The sophomores would rank as Green, but the juniors would rank as Yellow. The data is limited, but this may be a result of the somewhat chaotic situation which the students who have been at Millikin longer than two years found themselves in with regards to physics courses. We will have to see how these scores track over the next few years to be able to draw any substantive conclusions, however.

Goal 2 – Yellow Light

This is not based on quantitative data, but on grades and analyses of lab materials (lab books, etc.). The students in PY 245 (the equivalent to PY 253) did a reasonable job of data analysis and experimental design (probably rating around a 3), but were lacking in background research (probably rating around a 1). We will discuss plans for improving these scores in the next section.

Goal 3 – Green Light

This is not based on quantitative data, but on grades and discussions with students about lab materials, etc. The students in PY 245 (the equivalent to PY 253) did a fairly good job, overall, on their oral presentations, and I would rate them somewhere around a 9. As far as written presentations, I would rate them around an 8. The PY 253 course focuses on writing of scientific papers, something the students do not have much experience in. They write in teams, one producing a rough draft and then the other editing it, with roles switching for a second paper.

VII. Improvement Plans

For obvious reasons, the department is in a state of flux. Therefore, everything that exists in terms of curriculum, instruction, and assessment is under construction. Based on prior experience and a limited amount of data taken at Millikin, it appears that the above goals are reachable, assuming that appropriate levels of support are provided. For AY 2005-2006, we have added an additional hour to the weekly laboratory sessions for PY 201, 202, 226, 236, and 246 (as currently labeled) in order to better facilitate reflection and understanding of homework and lab concepts, and also to better integrate small-group active learning techniques into the curriculum. This was only moderately successful, since different faculty taught the lecture section and the lab sections, so that integration of the courses was incomplete. During the 2006-2007 AY, the department has synched up the lecture and lab for all courses, and the plans are that a greater integration of lecture and lab content will be possible. We also expect the increased time for homework and discussion will be an aid to the students.

Specifically focusing on the three learning goals, it is expected that the addition of a second full-time member of the department will make a significant difference in how material is taught. The lessening and alteration of the teaching load on me will allow me to focus more attention on the College Physics sequence, and perhaps re-think how some of that course is structured. Casey Watson will have a high contact load, but limited preps, and I am excited about the ideas he will bring to University Physics. One thing that the department has committed to is integrating new pedagogies as much as is reasonable in the courses; to that end, Casey is expecting to attend the New Faculty Workshop, sponsored by the American Association of Physics Teachers and supported by the National Science Foundation. At that workshop, he will learn about research-tested pedagogies from the primary researchers in the field.

Also, this will be the first year utilizing the new curricula and with the new faculty that there will be a full complement of students – freshmen through seniors. As such, this will be the first real test for the learning goals and teaching techniques at all levels. We expect that at the end of this year, we will be in a much better position to assess learning goals two and three, so as of now we cannot go further with analyses of these goals.

Appendix I – Curriculum Map

	Problem Solving	Experimentation	Communication
PY 100 – The Planets			
PY 101 – Stars and Galaxies			
PY 104/105 – Lab			
PY 106 – Physics of Sports	YES		
PY 111 – College Physics I	YES		
PY 112 – College Physics II	YES		
PY 151 – University Physics I	YES	YES	
PY 152 – University Physics II	YES	YES	
PY 253 – Modern Physics	YES	YES	
PY 262 – Experimental Physics I		YES	YES
PY 300 - Astrophysics	YES		YES
PY 303 – Physical Chemistry I	YES		
PY 304 – Physical Chemistry II	YES		
PY 352 – Theoretical and Analytical Mechanics	YES		
PY 362 – Experimental Physics II		YES	YES
PY 381, 382 – Advanced Topics in Physics	YES	YES	YES
PY 401 – Mathematical Physics	YES		
PY 403 – Electromagnetism I	YES		
PY 404 – Electromagnetism II	YES		
PY 406 – Quantum Mechanics	YES		
PY 481, 482 – Senior Research	YES	YES	YES