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 2010-2011 AY, the department rates student learning for goal 1 as Yellow, goal 2 as Green, and goal 3 as Green.

Respectfully submitted by Eric Martell, on 6/28/11.

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:

1. 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. 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. 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 2010-2011 AY by two full-time Assistant Professors, Eric Martell (chair) and Casey Watson. Dr. Martell received tenure and promotion during 2010-2011, and Dr. Watson will apply for the same during 2011-2012. Both faculty frequently carry overloads. 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.

The number of students who are physics majors has grown significantly over the past three years. As of Fall 2004, there was one sophomore and three freshmen physics majors. During the 2010-2011 year, we graduated three students, Bill Kersten, Kevin McNelly, and Justin Williams. In Fall 2011, we expect to have one senior, five juniors, four sophomores, and six to seven freshmen enrolled as physics majors.

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.

Research tells us that successful physicists are good at more than problem solving and doing experiments – they have to be good communicators (both orally and in writing) and be able to work as part of a team. Throughout our curriculum, our students are expected to develop each of these skills, eventually culminating in a near-professional performance during their Senior Research projects. In 2010-11, our students demonstrated what they had learned in a variety of ways. Nick Polley, a junior Physics and Applied Math major, worked with Dr. Casey Watson on a Leighty Scholars project (that continued into the Fall semester) which resulted in a paper entitled "Chandra X-ray Constraints on Sterile Neutrino Warm Dark Matter," currently in preparation for publication. Three senior physics majors performed year-long research projects: Justin Williams (working with Dr. Watson) studied supernovae, Bill Kersten (working with Dr. Watson) has developed a self-consistent theoretical model of Cepheid variable star pulsation periods, and Kevin McNelly (working with Dr. Martell) is using high-speed cameras to study the deformation of casters under heavy loads.

The curriculum reflects 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 curriculum matches up with departmental learning goals.

III. Learning Story

The typical Physics major at Millikin will take PY 151 and 152, along with the accompanying lab courses, PY 171 and 172, 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 mathematics. 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.)

Every course we teach above the freshman level is offered every other year (except for Senior Research, for obvious reasons). Therefore, the exact path a student will follow depends on whether they enter during an odd or an even year. Here, we explain what a student entering in Fall 2011 would take. As sophomores, Physics majors would take PY

262, Experimental Physics I, focusing on Electronics, which will introduce them to National Instruments' LabVIEW™, the industry and academic standard in experimental control and data acquisition. In the spring, they would take PY 362, Experimental Physics II, where they would focus on data acquisition and experimental design. 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.

During their junior year, physics majors will take PY 253, an introduction to Modern (20^{th}-century) Physics, and PY 325, Mathematical Physics. In Modern Physics, students will be introduced to Mathematica™, the most extremely popular and powerful computational and analysis software package, and in Mathematical Physics, they will focus on integrating knowledge from a variety of math classes as well as filling in gaps of material not commonly covered in traditional mathematics courses. They will also begin the process of learning how to write scientific articles as well as present their research orally in a seminar-style symposium. In addition, they will complete Theoretical and Applied Mechanics (PY 352) and Quantum Mechanics (PY 406).

As seniors, the only core physics courses left would be the two-term Electrodynamics sequence (PY 403/404), along with their Senior research project (PY481/482). The relative absence of physics courses from the senior year is intentional, so that students preparing to take the GRE in the fall of their senior year are as prepared as possible.

Along with these courses will be a number of math and other science classes, such as Physical Chemistry (cross-listed with Chemistry), 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.

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. Methods

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 are listed below (in terms of average percentile ranking for the overall scaled score):

- **Senior** Green: Percentile ranking ≥ 60 Yellow: Percentile ranking ≥ 50

For goals 2 and 3, we have developed rubrics 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 wherein students can reflect on their work and use the evaluations to improve their presentations and experimental design each year.

Note: In 2010, we modified the expectations for three of the following rubrics, since students take courses in different orders, it is more important to judge them based on the number of times they've done the work, not the number of the course. Because we have a small number of students, it is fairly straightforward to track which students fall into which category.

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 rubric for evaluation is as follows:

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 sophomore would be lower than that for a junior, etc. The departmental goals for each of the three courses are listed below:

- **Sophomores** Green: Course avg. ≥ 8 Yellow: Course avg. ≥ 6
- **Juniors** Green: Course avg. ≥ 10 (with no 1's) Yellow: Course avg. ≥ 8
- **Seniors** 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. These presentations will also frequently take place in PY 352, 403, 404, and 406, and when this occurs, the data will be gathered for analysis as well. The rubrics for evaluation are as follows:

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 sophomore would be lower than that for a junior, etc. The departmental goals for each of the three courses are listed below:

- **Sophomores** Green: Course avg. ≥ 8 Yellow: Course avg. ≥ 6
- **Juniors** Green: Course avg. ≥ 10 Yellow: Course avg. ≥ 8
- **Seniors** 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 sophomore would be lower than that for a junior, etc. The departmental goals for each of the three courses are listed below:

- **Sophomores** Green: Course avg. ≥ 8 Yellow: Course avg. ≥ 6
- **Juniors** Green: Course avg. ≥ 10 Yellow: Course avg. ≥ 8
- **Seniors** Green: Course avg. ≥ 12 (with no 1's) Yellow: Course avg. ≥ 10

V. Data

For goal 1, the FCI was administered during Fall 2011 to 21 PY 151 students. The average pre-test score was 10.1, the average post-test score was 20.2 (the highest we've recorded in seven years, just above last year's 19.9), resulting in an average percent gain of 51.7% (well above our previous high of 39.9% in 2010, and even further above the national average).

The Physics MFT was administered at the end of the Spring 2010 semester to nine physics majors (three seniors, one junior, and five sophomores) and one physics minor. The average scaled score was 128.8 for sophomores (128 in 2010, 120.5 in 2009, 139.7 in 2008, 126.5 in 2007, and 135.5 in 2006), 125 for juniors (131 in 2010, 145.5 in 2009, 138.5 in 2008, 136, and 138.5), and 133 for seniors (160 in 2010, 132.5 in 2009, 156.3 in 2008 and 133 in 2007). The average introductory physics score was 29.2 (23.5, 20.5, 27.7, 27.5, and 35.8) for sophomores, 23.5 (27, 43, 34, 33.3, and 36) for juniors, and 35 (57, 30, 52, and 26) for seniors. The average advanced physics score was 30 (35.5, 24, 50, 28.5, and 36.3) for sophomores, 29.5 (37, 47.5, 44.5, 40, and 41.5) for juniors, and 34 (61, 37, 59, and 43) for seniors.

For goal 2, we applied the above rubric to the experimental designs in PY 362. This was the first time we used the rubric for any course other than senior research. The scores for 2011 were 10.4 for sophomores and 10.7 for juniors. There was only one student in PY 481/2 who performed experimental research, and his score on the rubric was 10.

For goal 3, we applied the above rubrics for written and oral presentations to students in PY PY 362 and PY 482. The results were as follows:

Sophomores:	Written Average = 12.4 (compared with 12 in 2010)
	Oral Average = 11.7 (compared with 11 in 2010)
Juniors:	Written Average = 12 (compared with 12 in 2010)
	Oral Average = 12 (compared with 10.9 in 2010)
Seniors:	Written Average = 12.7 (compared with 13.8 in 2010)
	Oral Average = 12.3 (compared with 14 in 2010)

VI. Analysis

Goal 1 – Yellow

This was a very mixed year for this goal. The students in Dr. Watson's PY 151 class did exceptionally well on the FCI, and a gain of 52% is remarkable. On the other hand, the senior class did quite poorly on the MFT, with average percentiles of 1, 20, and 10 in the three categories. Note: This was a particularly weak senior class, and their scores across the board were disappointing in virtually every category, so we do not look at this as indicative of a significant problem with the program.

Goal 2 – Green

The sophomore and junior students evaluated in PY 362 both rated as Green in this category, while the student in PY 482 rated as Yellow; the preponderance of evidence indicates that we should rate this as Green. On a pedagogical level, Dr. Martell realized during the class that our students needed more deliberate instruction on experimental design than was planned, even though they scored well on the rubric, and between now and the next time we teach the class, we will work with faculty from across the sciences to do so. We expect that the rubric for this category will also evolve for the future.

Goal 3 – Green

At the sophomore, junior, and senior levels, the students' written and oral presentations average out to green in every category. Perhaps more impressively, every score by each student used as part of this assessment rated as green. The consistently higher marks for more advanced students indicate both a deeper understanding of the material and a refinement of their oral and written presentation skills. The trend lines are fairly flat (a small dip for the seniors is related to the graduation of an excellent student and the aforementioned weak senior class), but since they are rating very high, that's a perfectly acceptable outcome.

VII. Improvement Plans

Goal 1: We expected the FCI scores to continue to improve in Fall 2011, and they did. Dr. Martell will teach the course in Fall 2012, and given the success he's had in improving his students' performance on the FCI, we expect that the scores will continue to be high. Recent history for the FCI indicates that nothing significant should change in our approach to this material. The MFT is a different story. Beginning in the 2008-2009 AY, we focused more of our efforts on training our majors to deal with multiple-choice tests, as they will see on the GRE (for example). The MFT is designed to correlate with the Physics subject section of the GRE, so not only does it measure our students against nationally established baseline, but it also relates to their ability to get into graduate school. In prior years, the MFT was the only multiple choice test they saw all year, as we focus on problem solving and integration of knowledge. Our improvement plans included two things – a series of voluntary tutoring sessions for students planning on taking the GRE, so we can focus on individual students' particular deficiencies and prepare them for the test, as well as the integration of some multiple-choice questions, taken from GRE practice books and similar texts, into each advanced course, including instruction on how to approach the questions. We strongly believe that the problem-based approach produces stronger physicists; however, the GRE (and similar tests) is a necessary hurdle for students interested in advanced study, and our data now indicates a significant improvement in their performance on the MFT. We will have to see whether that translates to high scores on the GRE. We will also be working with our students interested in pursuing grad school to help them prepare for the GRE, and we expect that this focused work will improve performance on the MFT as well.

Goal 2: As mentioned earlier, while our students generally did well on this goal, it felt somewhat hollow. It is clear that they need more extensive instruction on experimental design, and we will work with faculty from Biology and Chemistry to incorporate that into our courses beginning in 2011-2012.

Goal 3: Our students are already quite successful at written and oral communication, and we will maintain the emphasis on both in the vast majority of our advanced courses. Additionally, we have incorporated a more significant writing component in our introductory lab courses (PY 171 and 172), which will hopefully help students build a stronger foundation earlier in their college careers.

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 111/171 – College Physics I	YES		
PY 112/172 – College Physics II	YES		
PY 151/171 – University Physics I	YES	YES	
PY 152/172 – 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 401 – Mathematical Physics	YES		
PY 352 – Theoretical and Analytical Mechanics	YES		YES
PY 362 – Experimental Physics II		YES	YES
PY 381, 382 – Advanced Topics in Physics	YES	YES	YES
PY 403 – Electromagnetism I	YES		YES
PY 404 – Electromagnetism II	YES		YES
PY 406 – Quantum Mechanics	YES		YES
PY 481, 482 – Senior Research	YES	YES	YES