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 2013-2014 AY, the department rates student learning for goal 1 as Yellow/Red, goal 2 as Green, and goal 3 as Green.

Respectfully submitted by Casey Watson, on 7/01/14.

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 2013-2014 AY by two full-time Associate Professors, Casey Watson (chair) and Eric Martell. Both faculty have frequently carried overloads in the past, but we have sought to remedy this recently by reducing the hours required for introductory physics labs (PY 171 and 172) from 3 hours to 2 hours per lab. We were able to accomplish this reduction without the loss of educational value to the students by using innovative, new pedagogical techniques and devices in the lab. These will be detailed in Eric's annual evaluation. 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 2012-2013 year, we graduated **six students**, Joe Cheeney, Bret Henderson, Eddie Pluhar, Chris Pelikan, Nikki Tipsword, Jamiahus Walton, and in the 2013-2014 year, we graduated **five students**, Brian Barry, Josh Monroe, Brad Rucker, Syed Salik, and Liyang (Leon) Yu. Brian is taking his actuarial exams, Josh plans to apply to continue doing dark matter research with Casey and then apply to graduate programs in physics this fall, Brad is working with his father – who works with solar cells, Syed is attending medical school, and Leon plans to combine his physics and business training. Due to the large numbers of graduates in our two most recent classes, our numbers are down a bit, but still far exceed the one major we had in 2003. In Fall 2014, we expect to have three seniors, three juniors, two sophomores, and five freshmen enrolled as physics majors.

Most students who pass through courses in Physics or Astronomy are not physics majors, but part of the department's extensive service to the University (typically at least 100 non-major student enroll in our introductory physics and astronomy courses each semester). In addition, because of our excellent astronomical facilities, 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 must acquire more than just problem-solving and experimental skills to be successful – they must also 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 all of these skills, eventually culminating in a professional-level performance during their Senior Research project(s) and the final presentations on their findings. In 2013-14, our students demonstrated what they had learned in a variety of ways. Four of our graduating seniors presented their research at the Millikin Undergraduate Poster Symposium, and three of them presented at the 2014 April Meeting of the American Physical Society – a national stage attended by thousands of physicists. (Two juniors and a sophomore also presented research at this national meeting).

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 are accompanied by MA 140 and 240, Calculus I and II, as co-requisites, since the primary language of doing physics is mathematics. The PY 151/152 and 171/172 series involve the lecture and laboratory components of the physics experience, respectively, and heavily integrate modern pedagogy, specifically active learning, peer instruction, and inquiry-based methods. (These methods are also used heavily in our other introductory courses - PY 100 and 101 and PY 111 and 112, which primarily serve non-majors, and are even incorporated (to a somewhat lesser degree) in our advanced courses as well.)

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 s/he enters during an odd or an even year. Here, we explain what a student entering in Fall 2014 would take. As sophomores, Physics majors would 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 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. In both of these 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.

During their junior year, physics majors will 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. In addition, they will complete the two-term Electrodynamics sequence (PY 403/404).

As seniors, the only core physics courses left would be Theoretical and Applied Mechanics (PY 352) and Quantum Mechanics (PY 406), 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 and all students have ample time to complete their capstone research projects.

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 allows 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 each student is on the right track. The primary goals are to enable each student to graduate in a timely manner with courses that reflect that student's interests and needs and enable him or her to pursue whatever post-graduate course they choose, whether it be 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 the curriculum, so that a satisfactory result for a junior will be higher than that for a sophomore, 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 the curriculum, so that a satisfactory result for a junior will be higher than that for a sophomore, 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 the curriculum, so that a satisfactory result for a junior will be higher than that for a sophomore, 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 the curriculum, so that a satisfactory result for a junior will be higher than that for a sophomore, 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. <u>Data</u>

For goal 1, the FCI was administered during Fall 2013 to 17 PY 151 students. The average pre-test score was 8.9, the average post-test score was 16.5, resulting in an average percent gain of 36.2%. This is a solid result – well above the national average, but falls below the 50% level gains achieved in recent years. Eric tells me he tried some new pedagogical techniques in 2014, and – based on these results – I'm sure he'll adjust his methods accordingly.

The Physics MFT was administered at the end of the Spring 2014 semester to eight physics majors (four seniors, three juniors, and one sophomore). The average scaled score was 131 for sophomores (vs. 139 in 2013, 134 in 2012, 128.8 in 2011, 128 in 2010, 120.5 in 2009, 139.7 in 2008, 126.5 in 2007, and 135.5 in 2006), 133 for juniors (vs. 137 in 2013, 142 in 2012, 125 in 2011, 131 in 2010, 145.5 in 2009, 138.5 in 2008, 136, and 138.5), and 140 for seniors (vs. 138 in 2013, 127 in 2012, 133 in 2011, 160 in 2010, 132.5 in 2009, 156.3 in 2008 and 133 in 2007). Comparing to our previous results, we see that the average scores were typical for sophomores, low for juniors, and high for seniors.

The average introductory physics score was 29 (vs. – in the same years as above – 39, 35.5, 29.2, 23.5, 20.5, 27.7, 27.5, and 35.8) for sophomores, 34.3 (vs. – in the same years as above – 41.6, 37.9, 23.5, 27, 43, 34, 33.3, and 36) for juniors, and 42.8 (vs. – in the same years as above – 42.8, 21, 35, 57, 30, 52, and 26) for seniors. Comparing to our previous results, we see that the introductory scores were typical for sophomores and juniors but high for seniors.

The average advanced physics score was 37 (41.7, 34, 30, 35.5, 24, 50, 28.5, and 36.3) for sophomores, 36 (33.4, 46.4, 29.5, 37, 47.5, 44.5, 40, and 41.5) for juniors, and 38 (35.5, 37, 34, 61, 37, 59, and 43) for seniors. Comparing to our previous results, we see that the advanced scores were high for sophomores, low for juniors, and typical for seniors.

For goal 2, we applied the above rubric to the experimental designs of seniors completing experimental research projects. (PY 262 and 362 were not offered during AY 2013-2014). The results were as follows:

Seniors:	13.0 (Senior Research)

For goal 3, we applied the above rubrics for oral presentations of students in PY 253 and PY 325 and both oral and written to students in PY 482. The results were as follows:

Sophomores:	Oral Average = 12.3 (compared with 11.3 in 2013)
Juniors:	Oral Average = 13.0 (compared with 12.75 in 2013)
Seniors:	Oral Average = 14.0 (compared with 13.33 in 2013)
	Written Average = 13.5 (compared with 13.25 in 2013)

VI. <u>Analysis</u>

Goal 1 – Yellow/Red

The students in Eric's PY 151 class fell short of green this year, but only by a few percent, with a gain of 36.2%. As mentioned above, Eric plans to revamp his use of new pedagogical techniques in future semesters, based on what worked and what didn't this academic year. The senior class did poorly on the MFT, with percentiles of 24, 30, and 17 in the three categories – although this is an improvement over last year's results: 9, 28, and 4. However, small number statistics greatly affect the results. This year, one student did well, with a majority of scores at or above the 50th percentile, while the other three students did poorly across the board.

Goal 2 – Green

The one senior with an experimental research project met the minimum standards for Green for this category.

Goal 3 – Green

At the sophomore, junior, and senior levels, the students' 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, as has been the case every year we've done this assessment. 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 showed a small dropoff in some areas this year, but since they are rating very high, that's a perfectly acceptable outcome.

VII. Improvement Plans

Goal 1: The FCI scores dropped off a bit to 36.2%, but the hope is that Eric's classes will bounce back in future semesters to the 40-50% range. The MFT is a different story. Our results vary widely, and seem to be overly affected by a single student succeeding or failing, so it is hard to draw substantive conclusions from the data. One thing we suspect is occurring is that some students do not take the test as seriously as we'd hope, given that the test currently is given outside of any classes, so there are no consequences either for high or low scores. Starting in Spring 2015, we will tie the tests to courses (the specific details are still under discussion), and hopefully we will be able to get the students to focus and do as well as they can, without adding unnecessary stress at the end of the semester.

Goal 2: PY 362 continues to be a work in progress, but this year, the students performed well enough to qualify for a green rating for the goal. Dr. Martell attended a workshop during June 2013 designed to help improve the content of the Experimental Physics sequence, and the expectation is that such activities will continue to improve the courses.

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