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, the GRE physics subject 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 2016-2017 AY, the department rates student learning for goal 1 as Yellow, goal 2 as Green, and goal 3 as Green.

Respectfully submitted by Casey Watson, Chair of Physics and Astronomy.

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 2016-2017 AY by one full-time Associate Professors, Casey Watson (chair), and Visiting Assistant Professor, Robert Chamberlain. 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 physics majors has remained fairly steady over the past three years. during AY 2016-2017 we had 13 physics majors and graduated two students: Zechariah Miller and Ben Woodall. Zech is working as an engineer in Memphis, TN, and Ben is doing software design in Chicago. In Fall 2017, we will have three senior, two junior, two sophomore, and six freshmen physics majors.

Most of the students in our Physics or Astronomy courses are not physics majors, but are instead part of the department's extensive service to the University. (Typically at least 100 non-major students 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 2016-17, our students demonstrated what they had learned in a variety of ways. **Six students** (Takunda Jakachira, Zech Miller, Whitley Sapp, Hunter Somers, Andrea West, and Ben Woodall), including both of our graduating seniors, presented their research at both the 2017 March Meeting of the American Physical Society in New Orleans, LA – a national stage attended by thousands of physicists – and at the Millikin Undergraduate Poster Symposium, part of Millikin's Celebrations of Scholarship. Hunter Somers and multiple business majors also presented their BluSolar research on the cryogenic treatment and improved performance of monocrystalline silicon solar cells at the Startup World Cup in Silicon Valley and at the CleanTech University Prize Competition in Chicago, both in February 2017.

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 – though 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 2016 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(s) (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 40% - 50% 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 old versions of the GRE Physics Subject Test, created by the Educational Testing Service. The performance of our students can easily be compared to the statistical performance of the thousands of physics majors who took each previously administered GRE subject test we use – including the distributions of total scores and the fraction of correct responses on each individual question. 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.

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):

- **Soph.** Green: Percentile ranking ≥ 30 Yellow: Percentile ranking ≥ 20
- **Junior** Green: Percentile ranking ≥ 45 Yellow: Percentile ranking ≥ 30
- **Senior** Green: Percentile ranking ≥ 55 Yellow: Percentile ranking ≥ 40

(U.S. students who score above the 50th percentile on the GRE subject test are typically admitted to most {75%} of physics graduate programs. The higher percentiles are mostly populated by foreign students who essentially have Masters Degrees before applying to graduate schools in the U.S.)

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 2016 to 15 PY 151 students. The average pre-test score was 9.9, the average post-test score was 19, resulting in an average percent gain of 46.4%. This is an excellent result – well above the national average, and on par with expectations for gains associated with best practices in physics instruction – group work, peer instruction, etc. (see above).

The Physics GRE Subject test was administered at the end of the Spring 2017 semester to eight physics majors (two seniors, three juniors, and two sophomores). The average percentile rankings were 22.7, 35.6, and 44.3, respectively for the sophomores, juniors, and seniors. These results are similar to those of the previous year – Yellow level.

For goal 2, we applied the above rubric to the project designs and work products (summary papers and poster presentations) of seniors completing dark matter research and the experimental designs of student-created projects in PY 362:

Sophomores:	13.1 (PY 362)
Juniors:	13.6 (PY 362)
Seniors:	13.8 (Senior Research)

For goal 3, we applied the above rubrics for oral and poster presentations of students in PY 262 and PY 362 (Experimental Physics I and II) and seniors for the senior seminar talks. The results were as follows:

Sophomores:	Oral Average = 12.2 (compared with 12.3 in 2016)
Juniors:	Oral Average = 13.0 (compared with 13.1 in 2016)
Seniors:	Oral Average = 13.7 (compared with 14.0 in 2016)
	Written Average = 13.5 (compared with 13.4 in 2016)

VI. Analysis

Goal 1 – Green/Yellow

The students in the PY 151 class achieved green status in AY 16-17. Upper level students performed at the yellow level on the GRE physics subject test.

Goal 2 – Green

The students in PY 362 achieved green level ratings for their project designs and the two senior research projects achieved Green status as well.

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 have 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.

VII. Improvement Plans

Goal 1: We hope to maintain or slightly improve the 16-17 FCI scores. (54% gains are the maximum we've ever achieved, so there isn't much more room for improvement beyond the 16-17 average of 46.4%.) The GRE Subject Test is a more difficult metric to analyze because of small number statistics. The average of our students was Yellow, but small variations in scores can have dramatic impacts on the mean in such a small group. As always, we will continue to do our best to reinforce the key concepts from each course that are evaluated on the subject test. Starting in Spring 2015, we decided to tie the test to course grades, and this seemed to help the students take the diagnostic tests more seriously than before. (Our previous results with the Major Field Tests were between Yellow to Red when we did not tie the results to a grade.)

Goal 2: This year, all the graduating seniors and PY 362 student performed superbly.

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	YES		
PY 101 – Stars and Galaxies	YES		
PY 104/105 – Lab	YES	YES	
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