II. Student learning goals

Reflecting the liberal arts nature of Carleton, we have shaped our program to serve physics majors, other science majors requiring a background in physics, and non-science majors desiring an introduction to physics or astronomy. One of our primary departmental goals has been to establish a strong sense of community among our majors and a welcoming learning environment for all students. Both the personal and intellectual growth of our students are important. We try to help our students become considerate group members, working together effectively to promote common learning goals. We want students to excel as individual learners, while also supporting and encouraging their peers.

In carrying out our mission, we have goals for the *knowledge* we would like students to acquire, the *skills* they should master, and the *experiences* we think they should encounter in learning and doing physics. The specific goals differ for the three student categories mentioned above. These goals are also flexible enough to accommodate the varied plans of students majoring in physics.

a. Knowledge

To be a physics major is to have knowledge of certain core subjects, as well as acquaintance with more specialized areas. Our core curriculum introduces students to key concepts in classical & quantum mechanics, electricity & magnetism, and thermodynamics, while also providing enough flexibility so that students with varied interests can tailor the program to meet their needs. For majors in other sciences, selected topics are covered at an elementary level, with an emphasis on understanding the physics mindset in approaching problem solving. For non-science majors, topic coverage is selective, and a greater emphasis is placed on the role of physics in our conceptual understanding of the universe and the ways in which that understanding has grown.

We want physics majors to be able to:

- Understand how physicists explore, model, and make predictions about the universe at a variety of scales.
- Acquire knowledge of key concepts in classical & quantum mechanics, electricity & magnetism, and thermodynamics.
- Apply and integrate physics knowledge and skills to understand real problems.

b. Skills

We expect our students, both majors and non-majors, to develop a number of skills while taking our courses. Some are general skills common to all areas of study at Carleton, including the ability to communicate clearly in written work and oral presentation, the ability to work effectively in a group, and the ability to continue learning on a largely independent basis. Other skills are more discipline-specific, and the extent to which they are taught depends on the level of the class. Introducing non-physics majors to the methods of physics will provide them skills and thought processes which will broaden and strengthen their intellectual endeavors in their own diverse fields.

We want physics majors to be able to:

- Use critical analysis and be able to approach, understand, and solve complex problems using effective problem-solving techniques.
- Use computational, experimental, and analytical approaches and techniques to analyze, test, and model systems.

- Communicate clearly in written work and oral presentation.
- Develop group work skills and employ team-based learning strategies.
- Find, evaluate, and cite appropriate sources of information.
- Acquire the ability to continue to learn on an independent basis.

c. Experiences

We want the experiences of students in our classes to be not only personally satisfying and intellectually rewarding, but also useful in preparing them for future work in or out of physics. For our majors, we want every student to have an experience working on a project that requires the student to engage in the process of doing research.

We want physics majors to:

- Engage in an open-ended project in physics, astronomy, or related fields.
- Research, write, and present on an independently chosen integrative physics topic.
- Gain an awareness of and preparation for career options in physics and related fields.

III. How do we achieve these learning goals?

The structure of our overall curriculum is designed to advance the goals outlined above. Core courses are sequenced in a way that balances the need for mathematical prerequisites, flexibility for first-year students undecided about a major or students who want to study off-campus, and our goal of introducing a diverse body of knowledge at an early stage. Intermediate-level courses in the major reinforce principles previously encountered, expand our students' knowledge base, and add details and complexity that enable students to use their physics to solve real-world problems. Courses emphasizing advanced knowledge in specific areas are electives and are not required for the major. Through coursework and scaffolded exposure to more challenging applications of core physics concepts, students begin to achieve the knowledge (Section II.a) learning goals we have for them. The skills (Section II.b) and experiences (Section II.c) learning goals are achieved through a mix of curricular and co-curricular experiences that are described below.

Apply and integrate physics knowledge and skills to understand real problems

One measure of students' mastery of content is their ability to integrate what they have learned and apply it to real problems, with unknown outcomes. There are several ways in which we provide students opportunities to do this. Many of our classes offer open-ended projects that give students significant lee-way to explore how concepts they learned in class can be applied to larger, more abstract problems. Several faculty members are also including academic civic engagement (ACE) opportunities in courses. For ACE projects, students work on campus or community projects related to course content. Students produce a final product to share with a community partner (via written, oral, or on-line methods) and submit it as part of their coursework. For example, projects have involved students partnering with the Northfield Environmental Quality Commission to work on community issues related to light pollution or an organics recycling program.

Beyond courses, research experiences, teaching opportunities, and internships provide excellent venues for students to apply and integrate their knowledge to use in a real world context. We encourage students to use summer and winter break to explore ways in which they can apply their physics and astronomy knowledge through work and research experiences.

Approach, understand, and solve complex problems using effective problem-solving techniques

Problem-solving skills are developed in every course we teach, and most courses include regular problem-solving assignments. Development of these problem-solving skills are supported in introductory and intermediate courses by making problem solving facilitators (students who have already taken the course) available to help students in departmental spaces during designated evening and weekend hours. As a department, we focus on helping students understand that problem solving is a process, not just about getting the correct solution. To this end, as a department, we expect students to write clear and thorough descriptions of their problem-solving strategies that include an outline of the problem, diagrams, a step-by-step description of their solutions, and ways to check if their answers are reasonable. We encourage students to work collaboratively on problem sets throughout the curriculum and provide our majors with keys to rooms in Olin to facilitate group study sessions. We encourage students to maintain a balance between their own growth as independent learners and their ability to collaborate.

Use computational, experimental, and analytical approaches and techniques

It is important that students become comfortable with computational, experimental, and analytical approaches to analyzing, testing, and modeling physical systems, and we try to include a mix of these approaches and techniques throughout the core courses for the major. An observational laboratory component is present in Astronomy 110, our course for non-majors, and all of our introductory physics courses have weekly four-hour labs. Beyond intro, three core courses for the major include weekly experimental labs. In addition to providing a "hands-on" appreciation of various physical phenomena, the experimental labs acquaint students with progressively more sophisticated apparatus, experimental methods, and techniques of analysis. Our lab curriculum could benefit from enhanced coordination to ensure that experimental skills are built appropriately and coherently throughout the major, and we also are interested in providing a more structured computational lab component in our curriculum.

Computational methods are primarily introduced in 5-week Phys 230 Computational Mechanics, though some of the introductory classes such as Phys 142 Matter & Interactions include a computational focus. At the intermediate and advanced level, *Mathematica* is the software package used for most of the computational work in the curriculum and students become quite proficient in this software. For students seeking additional background in computational methods, Phys 234 Computer Simulations in Complex Physical Systems is offered every other year. In the summer of 2014, Marty Baylor, Melissa Eblen-Zayas, and Bill Titus received a curriculum innovation grant from the College to explore ways to further integrate computational and experimental approaches in projects and courses throughout the curriculum.

Communicate clearly in written work and oral presentation

Communication skills are an element of nearly every course in the department. In our introductory classes, students often give mini-presentations while doing experiments or complete an oral check-out after lab. Our problem sets emphasize writing about how one solved a problem and describing the implications of the solution. Beyond the introductory level, written communication skills are developed through lab reports and research papers as well as through smaller informal writing assignments. In upper-level courses, it is common for students to work on individual or small-group projects, which culminate in a class presentation and/or a written paper. Our department used to offer a 2-credit course Phys 223 Presentation Skills in Physics, which was aimed at providing students with additional experience in oral presentation, both as presenters and as critical listeners. However, that course has not been offered recently, in part because of low enrollments and a move from a six-course teaching load to a five-course teaching load.

In the fall, we schedule a series of student talks where majors who have participated in research projects, teaching opportunities, or internships (both on and off campus) report on their experiences. The all-college student research poster session is also in the fall, and our on-campus research students are expected to present a poster describing their summer work. These venues provide students the opportunity to practice their written, visual, and oral communication skills.

Students must demonstrate the oral and written communication skills they have developed during their four years at Carleton in our senior Integrative Exercise (colloquially, “comps”). As part of comps, every senior writes a 7500 word paper, revised twice in response to comments from two faculty advisors and a peer reviewer, and gives a 60-minute public talk, which they also receive feedback on from faculty advisors and peer reviewers (described in more detail in Section IV.f).

Develop group work skills and employ team-based learning strategies

Group work skills are important and in various ways, we try to encourage cooperative learning. We encourage students to work together on homework problems and in study groups, as well as in traditional lab groups. Another way students learn to interact effectively with others is by working for the department as laboratory assistants, problem-solving facilitators, or graders. This work experience provides these students a revisiting of previously-studied subjects, and, more importantly, it puts them in a teaching role, where they can gain new perspectives on learning and develop effective ways of sharing their knowledge.

Finding information and continuing to learn on an independent basis

In a number of our intermediate and advanced courses, students engage in literature research on topics of their own choosing, and through these projects students must learn to find, evaluate, and cite appropriate sources. Connections with the library staff prove valuable in helping students with these skills, and we invite library staff to help with classes ranging from the first-year Argument and Inquiry seminar (described in IV.a) to comps. However, our department could better coordinate how we support the development of information literacy skills throughout the curriculum.

Engage in an open-ended project in physics, astronomy, or related fields

Providing students the opportunity to engage in curricular projects that simulate the exploration and uncertainty found in original research projects is a growing priority for our department. Currently, students in Phys 342 Contemporary Experimental Physics engage in a student-driven, four-week experimental research project, and we hope to introduce similar projects in Phys 335 Quantum Mechanics and Phys 346 Thermodynamics and Statistical Mechanics in the next couple of years so that students will experience both an open-ended experimental project and an open-ended computational or analytical project by the time they graduate.

We encourage any student who is interested to engage in research, the heart of the physics enterprise. Students have the opportunity to work with faculty members at Carleton either for credit during the academic year through special projects courses (Physics or Astronomy 356) or for a stipend as a summer research assistant (see Section IV.e). In addition, during the summer, many students take advantage of research experiences elsewhere through NSF Research Experiences for Undergraduates (REUs) or undergraduate internships at national laboratories. Experiences in such research settings depend heavily on a student’s ability to learn independently, to integrate various parts of their background, and to function well as members of a research group. For those students who are interested in teaching or other career paths, we help students find internships during the summer or projects during the academic year to explore their interests.

Research, write, and present on an independently chosen integrative physics topic

The structure of our senior comps is designed to develop, as well as assess, skills in library research, writing, speaking, and critiquing. In physics and astronomy, students choose comps topics in consultation with a faculty advisor. The comps paper and presentation are aimed at an audience of peers, and the goal is to integrate concepts from multiple classes in the major when presenting the topic. The process involves research in the primary and secondary literature. Success in comps is a test of a student's integration of knowledge, research and self-study skills, as well as writing and speaking ability. It also involves group interaction, with students listening to, questioning, and offering written criticism of each other's written and oral work (see Section IV.f).

Gain an awareness of and preparation for career options in physics and related fields

With the shrinking number of tenure-track academic positions for Ph.D. physicists, and a growing awareness in the profession of the many other ways a physics background can serve students, we have been trying to push our majors to consider a wide range of possible futures. The focus of these efforts is in the position of career advisor, filled by a faculty member who gathers, coordinates, and publicizes as many sources of career information as possible. While we certainly do not view the physics major primarily as training for a career, we think it is important that our graduates be as well informed as possible about the ways they can use their physics background other than the well-trodden route of the Ph.D. and university teaching/research career with which we faculty have the most direct experience.

One of our main tools for spreading career awareness is our 1-credit spring term course Phys 123 What Physicists Do. We invite speakers, often Carleton alumni, who provide examples of the broad variety of career options available to a student with an undergraduate degree in physics. The five speakers we bring to campus each spring showcase the work of "real world" practitioners of physics and astronomy. These talks, at their best, can be both inspirational (conveying the speaker's excitement about his or her field) and informative (providing an inside view of a particular job, and the associated career path to get there). (See Appendix A for a sample of recent Phys 123 speakers.)