Physics Department response to Provost's prompts on Undergraduate Curriculum & Student Experience: Fall 2015

The Department is proud of the well-recognized strength of its undergraduate program. Participation in our major has grown rapidly: by more than 50% in terms of the number of applicants desiring a physics major since 2009, and a doubling of the number of graduating majors in the past three years. At the same time, we have succeeded in the past three years in providing cutting-edge research experience to 70% of our majors, which we find to be an essential part of our students' professional preparation. Nonetheless, we strive for further improvements and innovations. The quality of the undergraduate curriculum and advising programs receive continuous attention by the faculty of the Physics Department. Three faculty committees are tasked with reviewing the curriculum and student experience for our majors courses and our introductory courses which serve several thousand students a year. In addition, the faculty holds a twice-monthly lunch meeting for the purposes of faculty mentoring and roundtable discussions of pedagogy, innovation, student professional development, and programmatic strategy. These continual studies and discussions are essential to improve our program and to accommodate the substantial growth in the number of physics majors.

In this document, we articulate responses to the specific prompts requested in Fall 2015 regarding the undergraduate Physics program. We also append the Department's 2014 document, *Undergraduate Strategy: Established Excellence and Planned Enhancements,* and the 2013 document, *Program Assessment and Learning Goals*. These documents provide a comprehensive description and analysis of undergraduate program in Physics, as well as the action plans currently underway.

Part One. Analysis of Current Curriculum

1a. Curricular coherence and accessibility

- The Department consistently offers a sequence of courses that develops the knowledge, skills, and experience that students need to pursue a variety of career options. Upon graduation, approximately two-thirds of our majors report that they will most likely enter employment, predominantly research in industry or national labs. Approximately one third attend graduate school (usually Ph.D.). A small minority pursues education careers. To facilitate this variety of post-graduate objectives, the Department offers three undergraduate program tracks:
    - Professional track (B.S. degree) – for students intending to continue onto a Ph.D. program in physics, or who want the strongest physics background.
    - Applied track (B.S. degree) – for students intending to work in industry or a graduate or professional program in a different discipline within science or engineering; this offers discipline diversity.
    - General track (B.A. degree) – for students wishing to teach K-12 science or to choose a career outside science or engineering

- Physics is a discipline steeped in participatory learning. As such, the Department offers many levels of hands-on laboratory learning experiences to students of all tracks that complement training in theoretical models and techniques. Two of our

lab courses at the sophomore and junior levels (Modern Physics lab 286 and Intermediate Lab 440) are not found among our peer departments and represent a key part of our undergraduate program. For the past three years, the Department has laid out a progression of skills to strengthen the coherence of the curriculum across the series of lab courses. We have identified a shortage of senior-level laboratory training as one of our priorities, as will be described below.

- For several years, the Department has worked to expand cutting-edge research opportunities for majors. Research experience offers an enormous step for students toward defining career plans, developing research skills for jobs and graduate school, cultivating faculty relationships for recommendation letters, and developing an independent reputation in research (as many of them become authors of published works). We are working toward a goal, in which every graduating major has research experience. We expose students to these opportunities in our Freshman colloquium, the First Year Research Experience program, our major advisors, our undergraduate physics club (Society of Physics Students), and our lab classes. We are proud of achieving 70% participation in faculty-guided research in the past three cohorts of graduating majors. Moving forward, we plan a new 500-level *Senior Research Experience* course, which will be described in part 1b that will serve as a capstone experience for students engaged in research as well as providing timely professional development on a weekly basis.

- *Current shortfall:* Due to the limited number of faculty, the department has not been able to provide a sufficient number of 500-level courses to meet fully the demand of our current undergraduate population. Similarly, we cannot accommodate the demand for 400- and 500-level lab courses due to inadequate teaching lab space. We target offering at least three 500-level courses (including at least one lab course) each semester.

- *Future Enhancements:*
  (1) Bolstered efforts on integrated professional development within the four-year program, to bring it to a level on par with the Department's coursework and research-education mission. This initiative will include the following systemic actions:

    - Professional development training as an integral part of the Freshman Colloquium course series, including such topics as: career choices, finding internships and research jobs, team-based learning activities to build proactive skills in communication, collaboration, creativity, and analysis.
    - Professional development consistently integrated into the Junior Year Writing in Physics course, for example by writing application cover letters.
    - A new junior-level colloquium course to include professional development. A companion to our Freshman colloquium, this new course

will help students choose and prepare for a career beyond the Bachelor's degree and further build professional skills. This preparation will include outside speakers from various career paths: industry, academia, government, Non-Government Organizations.

- A senior 500-level Senior Research Experience course that includes elements of professional development. This team-based learning course will complement individual faculty-mentored research by providing scaffolding for students, training them in collaborative research, literature searches, presentation, writing, presenting, research design and critical analysis. Furthermore, this course will guide students interested in non-research careers such as K-12 education, law, or science-related public policy *via* practica or internships with non-university partners.
- Further development of advising that is aligned with the in-course elements and including advice on the multiple career options available to physics degree holders. Advising includes targeted preparation for applying to jobs and graduate schools. (This year, for instance, we offered our first GRE-preparation sessions; we will continue these annually.)

(2) With the implementation of the new lab fee resources, the Department is updating its laboratory course curriculum to 21st-Century, state-of-the-art standards. This process will start with large-scale purchases of modern equipment. However, more teaching laboratory space and laboratory renovation are needed to realize this goal for the 400- and 500-level lab courses.

(3) In addition to the new 500-level on Senior Research Experience course mentioned above, the department plans to offer a new 500-level course *Data: The Art of Measurement and Analytics* focused on more sophisticated statistical tools and modern data analysis techniques such as machine learning which are increasingly critical skills in 21st Century science. This will be hands-on and compliment the Senior Research Experience as student will be able to directly apply these techniques to their active research.

1b. Clarity of communication

- Our recent and rapid increase in the number of majors posed a challenge for advising. Despite the large increase, we remain committed to providing every major (primary or secondary) with one tenure-stream faculty member as a four-year advisor. Each student meets with an academic advisor each and every semester to review the student's academic plan, prepare for upcoming class registration, discuss research opportunities, career plans, and any other matters that arise. Starting in Fall 2014, we doubled the number of faculty advisors, which we hope will result in improved evaluations of our advising by next year's seniors.
- Our academic programs are spelled out clearly in the undergraduate program handbook, available on the Department's website (http://www.physics.umass.edu/undergraduate).

- Opportunities for research, engagement, and professional development appear on the Department's website.
- The New Student Orientation and Transfer-student advising in the summer and January provide early guidance for students interested in entering the discipline of physics.
- *Current shortfall:* The most recent senior survey showed mixed opinions on "career preparation and guidance," with one third reporting in each of the categories of "very satisfied," "somewhat satisfied," and "somewhat dissatisfied."
- *Future Enhancements:*
  (1) A revision of the handbook is scheduled for Spring 2016 with a focus on advice for preparing for post-UMass jobs and graduate-school applications.
  (2) Professional development, as described above, in the form of workshops and more effective use of the Freshman colloquium to help support early integration of professional development.
  (3) More preparation and training given to undergraduate *advisors*. We will focus on training faculty on the needs of our majors (for example, without assuming that majors are headed to graduate school) and best practices for communication

1c. Class size goals by student level

- Over the last few years, the Department has seen a dramatic rise in the number of majors and the number of students requiring the service courses it offers to non-physics majors.
- Our Integrative Experience course (Physics 440) is both the culmination of our lab course sequence and an opportunity to integrate knowledge from lecture courses. To maintain a small class size, 12 per section, with our growing student body, we have doubled the number of sections to two per semester. This required devoting an additional FTE each semester, adding new equipment, and adding new experiments to the curriculum so that each group could work on projects without interruption. This course is routinely touted as the best of the major and the most important to their development. Part of the benefit of the course is the integration of experimental technique, writing, and professional development combined with small class size and one-on-one interaction with the instructors.
- Starting three years ago, we began routinely offering the Junior Year Writing Course in both the fall and spring semesters (whereas it had formerly been a fall-only course). This additional class is necessary to maintain the class size of 24 or fewer, and required the addition of an FTE to teach this course.
- Our four 400-level lecture classes often contain 50-60 juniors and seniors (an increase from 20-30 a few years ago). To provide the focused senior experience, we now look to our 500-level classes (often about 15 students in size) and our faculty-guided research experiences, as described above. Many of these latter experiences are one-on-one with faculty, or may involve a small number of similarly interested students. We believe these explain our fairly high senior evaluations in faculty accessibility (with 67% reporting 'very satisfied') in the face of expanded class sizes.

- *Future Enhancement:*
  As described in *1a* and *3b* (below), we aim to expand our capstone-level offerings with a more consistent and broader selection of 500-level courses.

Part Two. Goals for Student Learning and the Student Experience

2. Updates or revisions in light of the Campus Strategic Plan:

How objectives align with Strategic Planning Priorities, including diversity and internationalization

To meet the needs of its 21st-Century majors, the department strategy now emphasizes three pillars of undergraduate training, **Coursework, Research, and Professional Development**. The Department is incorporating modern research-based teaching techniques to enhance the student experience. Indeed, we have done so for many years: we find at meetings (*e.g.*, a recent Cottrell Scholars conference) that our undergraduate program is considered a national educational innovator as viewed by peers at other institutions and experts at the AAU. Specific current efforts include developing team-based learning (TBL) experiences and more fully integrating lecture and lab experience throughout the curriculum with a strong emphasis on effective pedagogy, excellent laboratory and research training, excellent training of TAs as co-instructors, and other educational innovations. The attached *Undergraduate Strategy: Established Excellence and Planned Enhancements* document articulates the philosophy and objectives. In Part 1 above, we discussed our assessment and specific goals for coursework, research and professional development aspects of our curriculum. Here, we address the specific points of Diversity and Internationalization.

- *Diversity.* The Department has had a Women and Minorities in Physics student group since 2007. Leading the group is an official departmental committee assignment that is not only assigned to women. The group changes its goals based on the faculty leadership, which enables different perspectives. Some incarnations focused on mentoring, others focused on outreach. Still others focused on scholarship and arming the students and faculty with data from research on women and minorities in science. The last few years has seen a rise in the diversity of our undergraduate students as our overall student enrollments have increased. In addition, the enrollment of Physics majors in our three different tracks indicate a diversity in career options.
- *Internationalization.* Most of our undergraduates are involved in research, which, due to modern collaborations with international groups and students from overseas, is inherently international. Research groups send many research-active undergraduates to national and international conferences where they obtain even more exposure to the international nature of physics research. The Department has recently set up a fund ($5k/yr) to provide partial support for our majors to attend conferences and workshops. Furthermore, the Department's advising structure supports undergraduate student travel abroad, working closely with students who wish to study abroad to design a curriculum to accommodate the experience.

Part Three: Curricular Revision Action Plan

3a. Actions within existing resources

- The continual development of curriculum to 21st-Century standards is under way with an emphasis on better coherence of curriculum and the student experience. Aspects of the planned professional development training are taking place within the confines of existing resources through modest changes in course emphasis.
- More consistent professional development components in our Freshman Colloquium and Junior Year Writing Course.

3b. Actions that can only be addressed with additional resources.

- Additional faculty members are needed to:
    - reach our goal for each undergraduate to have a research experience, internship, or teaching practicum.
    - Create a new junior colloquium course, focusing on career options and guidance.
    - Offer a requisite 500-level Senior Research Experience capstone with fewer than 35 students that will help prepare students for future careers.
    - Offer at least three 500-level courses (including at least one lab course) each semester, and a new 500-level course *Data: The Art of Measurement and Analytics*
- Additional TA support is needed to:
    - Offer undergraduates access to students and better grading in all courses. Physics courses above the 100-level have weekly assignments that can be many pages long. It is equivalent to writing a literature paper every week. We rely on TAs to grade these papers. When grading is done poorly, undergraduates' attitudes toward the course and the major are adversely affected. Currently, our TAs are taking on load far higher than any of our peer institutions (responsible for 2-3 courses). This is untenable and results in poor assessment and reduced learning gains for our undergraduates.
    - Enable a full array of TBL courses. Currently, the TBL format is used for the introductory majors sequence Physics 181 and 182, and the introductory life science majors course, Physics 131.
- To succeed in bringing the 400- and 500-level laboratory courses to 21st-Century standards, larger lab space is needed. This space is also necessary to accommodate the increased number of majors from other CNS and Engineering departments that take physics.

Department of Physics

Preliminary Comments on Undergraduate Education
Established Excellence and Planned Enhancements

Overarching Statement: The Department of Physics has two distinct, yet simultaneous, teaching missions focused on two audiences: (1) our physics majors who focus on physics mastery and (2) all other students of the university who require the quantitative reasoning skills provided by a physics education. In this document, we separately treat these two educational programs, designated, "Physics Majors" and "Service and GenEd Courses."

I. Physics Majors: Our mission is to attract and educate students in the conceptual knowledge, innovation and problem solving skills, and hands-on experience of Physics to make them motivated and successful leaders in their chosen field.

Established Excellence: The University of Massachusetts Department of Physics has an excellent track record educating physics majors in the following:

1. Our lecture-based courses, the core course offerings of the major, and the recommended trajectory the students take through the curriculum provides a thorough training of the professional physicist.
2. The required coursework in laboratory physics is more comprehensive than in most physics departments.
3. Our majors' courses are relatively small (12 at smallest – 100 at largest) allowing the faculty to have meaningful individual interactions with our students.
4. Many of our undergraduates have research experiences on campus or in summer programs (current count of 34 undergraduate researchers among 13 research groups).
5. The number of physics majors is growing (now about double what is reported in large well-known Midwestern universities). This is not a national trend, since many peer and aspirant universities have not reported similar increases in majors. It demonstrates that UMass Physics is becoming a destination of choice for college students with an interest in Physics.
6. Our first-year curriculum for majors is not being taught in the TBL format.

Enhancements: There are a number of possible enhancements we envision to make UMass Physics a destination of choice and to encourage more STEM students to major in Physics once arriving on campus including the following:

1. An **EPIC Goal** for our majors is to have every graduating physics major have a research experience before graduating. Such experiences include research experiences on campus in both theory and experimental research groups, independent study on advanced topics in theoretical fields or experimental work, Research Experiences for Undergraduates (REU, both on or off campus), student-led faculty-coached team research projects, internships in either research or innovative teaching.
2. In order to ensure that all students achieve a research experience and establish an excellent career trajectory, we plan to enhance student advising and professional development for our majors. Some proposed changes to benefit the students included:
    a. A 1-credit junior-level professional development course, to complement our freshman seminar; this will focus on the skills needed by professionals in technical fields.

   b. Another option would be to piggy-back 1-credit honors sections on professional development onto the courses that already work toward professional skills including sophomore level computational course (P281), junior-level writing (P381), and junior/senior level integrated experiences and advanced laboratory course, (I-Lab, P440).
   c. Enhanced advising will continue to shift the focus of advising sessions from simply what they should do in the major to what they want to do in life and how their courses can help them to achieve it. Discussions will include getting into research on campus, REUs, and internships. We will also be better able to identify students who are at risk of leaving the major or not following the preferred track.
   d. We currently do not have a continuation policy to help ensure student success in the Physics Major. (1) The Physics Major is very demanding, and many students who do not excel in the first year leave the physics major, and then continue in another STEM major, which we believe is a success for CNS as a whole. (2) We will consider the adoption of a policy that requires a threshold competence in mathematics courses to continue the major into the junior year. If adopted, this should enhance student success in upper division Physics or ensure the transfer of students to more suitable major where they can achieve better success.
   e. We can train undergraduates in professionalism and teaching through including them as paid undergraduate teaching assistants. We currently do this in a limited fashion, but we seek to increase the number of undergraduate TA students.
3. We seek to increase the contact between Physics Majors and faculty.
   a. Better advising, more research opportunities, and contact through working with undergraduate teaching assistants will enable more contact between Physics Majors and research faculty.
   b. Such contact can be formal, such as advising or research mentoring, or informal, such as mentoring groups and the Society for Physics Students (an undergraduate student organization).
4. We have been working over the past few years to further enhance the teaching laboratory experience for Physics Majors. We currently offer twice as many labs (7 offerings) as peer and aspirant institutions for Physics Majors, but we seek to create more cohesive curriculum for training in hands-on problem solving, measurement, and analytics.
5. We seek to offer more, broader advanced courses for undergraduate students to give them more exposure to different specialized fields in Physics. We currently require that our majors take 1 advanced topic course for the BS tracks. We would like to offer more advanced courses, especially those with laboratories.
6. Another **EPIC Goal** of the Physics Department Teaching includes creating a new 5th year Master's Program for undergraduates interesting in focusing on a specific topic in physics that would work for all tracks including the Applied Physics BS, Professional Physics BS, and the BA track. Having more advanced course offering in more specialized fields of physics will enable more students to take a 5th year master's curriculum in a particular field.

<u>At the undergraduate/graduate teaching interface</u>: Items 5 and 6 above impact both our undergraduate and graduate programs. Currently several of our graduate students (from Physics and other departments) enroll in the 500-level advanced undergraduate courses, especially when they did not acquire such learning in their own undergraduate experience. One new advanced course the department plans to offer is focused on the skills of acquiring and analyzing data, with a course title of "*Data: The Art of Measurement and Analytics*." This

course would complement a graduate level course on data analysis we already offer. Another **Epic Goal:** To meet the rapidly expanding career opportunities, we encourage a consortium of departments (Physics, Computer Science, Statistics) in CNS to offer a Masters degree in Data Science. Physics has a particular strength in emphasizing the importance of both *measurement* and *analysis* in the data science enterprise.

II. Service and GenEd Courses: The Physics department teaches upwards of 2000 students each semester between the service courses required by other majors and the Gen Ed courses we offer. We strive to deliver the best physics education experience that can be found anywhere in the country. For many students, these courses are foundational for developing critical thinking, quantitative analysis, and visualization skills.

Established Excellence: The University Of Massachusetts Department Of Physics has an exceptional track record educating the rest of the university:

1. Diversity of general education and service course topics routinely offered.
    a. Required by other majors
        - P131, P132, P151, P152, P100, P114
    b. General education courses
        - P115, P116, P117, P118, P120, P125, A105
2. Despite teaching a large number of students we strive to maintain a reasonable faculty-to-student ratio to preserve a quality learning experience
3. Our department has been and continues to be a leader with instructional innovation. We were the first or among the first for the following innovations;
    a. Active hands on learning through labs and demos
    b. Online HW – Owl
    c. Clickers – Class talk → PRS
    d. Tablet computers
    e. Lecture capture
    f. Blended learning
    g. flipped/inverted classrooms
    h. Team based Learning (TBL)
4. The department has a culture of teamwork and teaching excellence:
    a. Multiyear departmental support for weekly teaching workshop
    b. Transfer of materials and institutional knowledge from instructor to instructor
    c. Best practice transfer
    d. Service courses committee to stream line and improve service courses

Enhancements: We have developed a culture of continuous teaching innovation and excellence. Therefore, we envision even more we can do to improve our service/teaching role to the rest of the UMass community.

1. Using the department's unique position in the university to more clearly and effectively support and deliver the general education goals through delivering courses that:
    a. Are current and interesting to the wider community

    b. Demonstrate the application of math thus cultivating in learners the visualization of math
    c. Use dimensional analysis
    d. General problem solving skills
2. Expand *learning by doing* activities:
    a. Shrink the class sizes of the *large* service courses
    b. More TBL
    c. Using more current real world, quantitative and current literature
    d. More at-home, out-of-the-classroom experiments
3. Standardize to achieve efficiency without loss of quality
    a. Team based teaching and curriculum and procedures (efficiencies in teaching)
    b. Learning objectives (clearly identifying learning objectives for each course and design commensurately)
    c. Enhanced assessments emphasizing the processes of thinking
        i. Long answer (show work)
        ii. Show steps to solve vs the answers

Resources: To accomplish our enhancements, indeed to better deliver to our students what we are now stretched too thin to deliver in an optimal way, will require additional resources. These will be needed to (1) enhance the faculty count to allow additional courses to be taught by faculty members (an enhancement of the faculty count will also allow additional research opportunities for our majors), (2) enhance the number of teaching assistants to allow additional laboratory sections to be offered, and (3) increase the equipment infrastructure to allow modernization of the teaching laboratories and the lecture demonstration equipment. In addition, due to enrollment pressures and the desire for enhanced quality of laboratory offerings, it is essential that we have an expansion of the space that is used for the undergraduate laboratories at both the service course and the advanced levels.

Submitted on behalf of the Physics Department by Bob Hallock, November 4, 2014. This was crafted as a result of several discussions among the faculty led by Mark Tuominen, Jennifer Ross and Heath Hatch; those three did most of the crafting.

Program Assessment in the Physics Department

Articulate Student Learning Goals and Objectives:

- Broad global statement of our program goals. The goal of the physics major is to:
  1. teach students the science required to understand how nature operates at a fundamental level.
  2. teach students how to do experimental science in the laboratory, to work together effectively in teams, and to communicate results in oral presentations and journal style papers.
  3. provide students with the analytic training needed to approach and solve a wide variety of problems in science and engineering after graduation
- Department learning objectives:

Learning Objectives	181 +lab	182 +lab	281	282	284 + 286L	287+ 289L	421	422	423	424	440 lab	531 lab	553 lab	556	558	568
#1: Newton's laws of motion, and relativity	TH				TH		TH				AL					TH
#2: Principles of electricity and magnetism		TH						TH			AL	TH	TH		TH	
#3: Modern physics and quantum mechanics					TH					TH	AL			TH	TH	
#4: Thermal and statistical physics						TH			TH		AL				TH	
#5: Basic laboratory, integration of lecture and lab concepts	TH	TH			TH	TH										
#6: Advanced laboratory, teamwork, research communication											TH		TH			
#7: Computational and mathematical techniques	TL	TL	TH	TH			TH	TH	TH	TH	TH	TL	TL	TL	TL	TL
Integration across topics					TL	TL				TL	TH, AH	TH, AH	TH, AH	TH, AH	TH, AH	TH, AH

TH: Taught with a high level of emphasis
TL: Taught with a low level of emphasis
AH: Assessed with a high level of emphasis
AL: Assessed with a low level of emphasis

Student Assessment:

- Direct measures of student assessment
  i. Performance in the upper-level majors courses
  ii. Performance in the 440 Intermediate Lab course, and student feedback through the Integrative Experience essay
  iii. Participation in undergraduate research
  iv. Student feedback to major advisors in one-on-one meetings
  v. Honors thesis capstone presentations
  vi. Senior survey

- Indirect measures of student assessment
  i. Retention of students in the physics major
  ii. End-of-year departmental awards and prizes
  iii. Placement of students into jobs and graduate programs

This table presents how these assessment measures can be used to quantify success in attaining the three goals for our majors.

Assessment measures	Goal 1	Goal 2	Goal 3	Use of the information
Performance in the upper-level majors courses	yes	yes	yes	As student success in the upper-level majors courses depends crucially on student learning the introductory courses, upper-level course instructor feedback to the faculty provides key assessment information on the effectiveness of the entire majors sequence.
Performance in Physics 440 ILab, and student feedback through the Integrative Experience essay	yes	yes	yes	Instructors of this course, generally taken in the students senior year, develop a very good sense of what students have learned in the major, their ability to innovate, and solve problems. This course serves as our IE Gen-Ed component with the addition of a student paper assessing the entire majors experience.
Participation in undergraduate research	yes	yes	yes	Research mentors get a very good sense of what students have learned in the major, their ability to innovate and solve problems
Student feedback to advisors in one-on-one meetings	yes	yes	yes	Every physics major has a minimum of two yearly meetings with a class advisor who follows the progress of the same group of students over the entire four-year program. The class advisors are members of the UG CC, providing input for changes to the curriculum as needed.
Honors thesis presentations	yes	yes		Two faculty members serve as chair and co-chair at these presentations. To effectively use these

				presentations as an assessment tool, the department should develop a Rubric for scoring.
Senior survey	yes	yes	yes	Results from these surveys were key input to the 2012-2013 departmental review of its undergraduate program.
Retention of students in the physics major	yes	yes		
Departmental awards and prizes	yes	yes		All students that are candidates for departmental awards are discussed by the physics UCC.
Placement of students after graduation	yes	yes	yes	Information comes primarily from the student-teacher/research supervisor connection, and mostly stays at that level. Department needs to formalize an assessment method.