AC 2007-2555: REDESIGNING A MAJOR: A CASE STUDY OF A CHANGING CURRICULUM

Jonathan Bougie, American University

Philip Johnson, American University

Nathan Harshman, American University

Teresa Larkin, American University

Michael Black, American University

Redesigning a Major: A Case Study of a Changing Curriculum

Abstract

This paper presents a case study of a significant change and reorientation in the curriculum and course progression of a physics program at a national university. Faculty designed this new curriculum based on comparative research of 22 undergraduate programs in physics. Data from this study includes course offerings, physics-major requirements, and electives offered from two major categories of institution: national universities without graduate programs in physics and national liberal arts colleges.

The reorientation in the program included modifying and extending course offerings, and adding a new "track" for students, allowing them to choose a concentration within the physics major based on their future plans. These changes were designed to provide students with increased knowledge of physics and technical, scientific, and academic skills required to achieve success in later academic programs or in technical fields in the workforce. The skills targeted were selected based on national trends in employment of physics degree recipients.

We present an assessment indicating the progress of this program based on increased numbers of enrollment, retention, and graduation of physics majors and minors; and post-graduation surveys. This assessment occurs in the third year of an ongoing six-year plan, and we are continuing the process of implementing the planned changes and assessing the results of these changes. Based on the progress of this program so far, we believe that the success of this reorientation could serve as a model for science and engineering programs at other institutions.

I. Introduction and background

This paper presents a case study of significant changes to the curriculum and course progression designed to reinvigorate the physics program at American University (AU). In the 2003-2004 academic year, the physics program at American University was relatively small and had experienced a decline in size in recent years. The physics program had previously included the M.S. and Ph.D., but these were phased out over the past decade due to budgetary and other concerns. At present, the program offers only a B.S. in physics. In addition, recent physics enrollment was markedly low, with only one physics major graduating in the 2001-2002 academic year, three graduating in the 2002-2003 academic year, and two graduating in the 2003-2004 academic year.

American University was not alone in this experience. According the American Association of Physics Teachers (AAPT), the number of physics majors steadily declined throughout the 1990s, although this number has increased since reaching a low in 1999.[1] However, the declining trend in the last decade was not universal. As the AAPT reported in their Strategic Programs for Innovations in Undergraduate Physics (SPIN-UP) report, "[I]n the midst of this decline some departments had thriving programs."[2]

In their report, the AAPT identified the following four factors as being held in common by physics programs that grew or maintained high levels of success during this same time period:

• A widespread attitude among the faculty that the department has the primary responsibility for maintaining or improving the undergraduate program. That is, rather than complain about the lack of students, money, space, and administrative support, the department initiated reform efforts in areas that it identified as most in need of change.
• A challenging, but supportive and encouraging undergraduate program that includes a well-developed curriculum, advising and mentoring, an undergraduate research participation program, and many opportunities for informal student-faculty interactions, enhanced by a strong sense of community among the students and faculty.
• Strong and sustained leadership within the department and a clear sense of the mission of its undergraduate program.
• A strong disposition toward continuous evaluation of and experimentation with the undergraduate program.[2]

The difficulties experienced by the American University physics program led to the re-evaluation of our program in light of the needs of potential physics majors who could be attracted to our department. Due to this re-evaluation, we significantly restructured our course offerings and requirements, as well as implemented other changes in our program. This study could potentially to be adapted for other physics, engineering, or technology programs, particularly those seeking to restructure after the loss of a graduate program and making a transition to an undergraduate-only program.

In Section II of this paper, we present the methodology used to evaluate our program and to identify possible changes that would help our students. Section III describes the changes made to the program in light of the considerations raised by the evaluation. Finally, Section IV shows preliminary assessment results which indicate the success of these changes.

II. Methodology

a. Expectations for post-graduate plans

To identify goals a department should set for educating physics majors, it is important to consider what outcomes students are expecting. According to a recent American Institute of Physics (AIP) Report, "Five to eight years after graduating, about 25% of physics bachelors have master's degrees and are in the workforce. Almost 40% of these have master's degrees in physics or astronomy, about 40% have master's degrees in other sciences and engineering, and 20% have master's degrees in non-science fields."[3] Of physics majors getting advanced degrees, less than half of these proceed to academia; most that do not, go into technical fields. The remaining one-third of bachelor degree recipients get no further degree and go directly into the workforce; three-quarters find a position that can be classified as having some sort of scientific capacity (the largest group, about a quarter, in software). Very few (about 2%) go into pre-college education.[4]

Based on these AIP statistics, the following goals for the physics major should be considered:

- Provide students with knowledge of physics.

- Provide students with technical skills such as familiarity with modern laboratory equipment, technical writing, and computer programming.
- Provide students with the experiences and skills necessary for them to do scientific work independently and within larger groups.
- Provide students with the academic skills required to achieve success in later academic degree programs.

The physics curriculum should have adequate options to prepare students for graduate work, but also be flexible enough for students to get a solid foundation in physics. In addition, an opportunity to develop the skills required of a scientific thinker and researcher is vital to any physics program.

b. State of the program at the time of evaluation

With these goals in mind, we began by evaluating the physics program as it was structured at the time in order to identify changes that would be beneficial to the program. We began by examining the course load and major requirements to determine whether the requirements for a major at American University were appropriate to the skills and background expected of physics majors. Part of this assessment was comparing these requirements to those of comparable universities across the nation.

Prior to the 2003-2004 agademic year, physics majors had the option of following one of two tracks: applied (chemical) physics or computational physics. Both tracks required six physics courses (see Table 1), four math courses, and two computer science courses. The applied physics track required three additional chemistry classes, and the computational physics track required three additional computer science courses. The total number of required credit hours for a B.S. in applied physics was 53, and the total number of required credit hours for a B.S. in computational physics was 51.

Table 1. Course Requirements for the Physics Major 2003-2004

Course Topics	Number Required
Introductory physics with lab (2 semesters)	2 courses
Modern physics	1 course
Classical mechanics	1 course
Electromagnetism	1 course
Advanced laboratory	1 course

A major weakness during the evaluation period was the lack of availability of other advanced courses. A number of upper-level courses listed in the course schedule, including (Advanced) Mechanics, Electromagnetic Waves, Basic Concepts in Statistical Physics, and Introduction to Quantum Mechanics were not required and were not offered regularly, meaning that they were effectively unavailable for most students.

c. Identification of other programs for comparison

A major tool in assessing the physics program was to compare the program at American University to programs at similar institutions. We began by identifying similar institutions as a measure of accepted national standards and as a baseline to which we could compare the program at AU. These institutions were identified for comparison on the basis of American University's status as a national university known as a liberal arts institution that offers a B.S. in physics but lacks a physics graduate program.

The first category for comparison was identified as private national universities of similar academic stature and reputation that offer the B.S. degree in physics but do not have a graduate program. A list of these was generated from the *U.S. News and World Report Annual College Guide*.[5] American University appears in the category of national universities and is ranked in the second tier. We checked all private universities in this category to see whether they had a graduate program in physics, and eleven of them (besides AU) did not. We thus used all eleven of these universities in our survey.

The second category for comparison is national liberal arts colleges. The validity of this comparison is based on similarity of program size, lack of graduate education, lack of engineering programs (usually, although many offer pre-engineering programs as does AU), and similar student preparation and motivation. A list of eleven schools with respected physics programs was chosen from the top two tiers of the *U.S. News and Worlds Report Annual College Guide* list of national liberal arts colleges.[5] The full list of colleges selected are listed in the appendix.

d. Identifying standards from comparison to national universities

Of the eleven selected national universities, all offered a traditional (i.e., graduate school preparatory) B.S. degree in physics, a degree which was lacking in our program. Four of these schools also offered a B.A. degree in physics. In addition to the traditional physics degrees, seven offered concentrations within physics, the most common being engineering physics (four institutions, often in conjunction with a 3-2 engineering program coordinated with another university). Other specializations were computational physics and mathematical physics (two programs each), and also medical, pre-med, secondary education, material science, and geophysics (one program each).

For each selected university, the university website was examined to find the course requirements for physics majors. For a B.S. degree, the number of physics courses required ranged between 10 and 15, with the average at 12.5 courses, not including single credit courses such as "Departmental Seminar" and "Careers in Physics." The average number of mathematics co-requirements was four courses. Additionally, nine schools required at least one chemistry course, and four required at least one computer science course. Certain interdisciplinary concentrations reduced the number of physics requirements but increased requirements in other departments. A typical number of required physics courses in such cases was nine. Typical B.S. major requirements in physics are shown in Table 2. Some programs also required supervised research, and many programs offered other upper level electives.

Table 2. Typical list of required courses for physics majors at national universities

Course topic	Number of courses required
Introductory physics with lab	2 courses
Modern physics with lab	1-2 courses
Waves and optics	0-1 courses
Classical mechanics	1 course
Electromagnetism	1-2 courses
Quantum mechanics	1 course
Statistical mechanics and thermodynamics	1 course
Advanced laboratory	1-2 courses
Electronics	1 course

Based on this comparison, the physics course requirements for AU were significantly less than the requirements of other institutions. The program at AU compensated somewhat by requiring additional courses in either computer science or chemistry, corresponding to the choice between computational and applied physics, but this neglected important parts of the basic physics curriculum. Of particular note was the absence from the requirements of quantum mechanics, statistical mechanics, electronics, and waves and optics.

Corresponding to the differences between the AU program and a more traditional physics program, we identified the choices provided by the track structure as an advantage of our program that we wished to retain. However, we concluded that the lack of a traditional physics B.S. (which forced students to choose between computational and applied physics) was a marked weakness of our program.

e. Identifying standards from comparison to liberal arts colleges

All eleven liberal arts colleges identified for comparison offer a physics major; typically a B.A., but a B.S. at the two institutions that also have engineering programs. There were no "tracks" except honors at such programs. The number of courses required for the major varied from 8 to 13 and an average of nine, with all but the two B.S. programs recommending (but not requiring) additional coursework for those students preparing for graduate school (usually two or three extra courses). The average number of mathematics co-requirements was three courses, and typically there were no other co-requirements. Some programs also required supervised research, and many offered other upper-level electives. Typical major requirements listed on the websites of these programs in physics are shown in Table 3. Some programs also required supervised research and/or offered other upper level electives.

The AU requirements were much closer to the requirements at liberal arts colleges than they were to those at national universities. However, in comparison to the requirements at liberal arts colleges, the number of physics courses required at AU was still lower than the average. Many, but not all, liberal arts schools required statistical mechanics, electronics, or waves and optics. Quantum mechanics was a standard requirement.

Table 3. Typical list of required courses for physics majors at liberal arts colleges

Course topic	Number of courses required
Introductory physics with lab	2 courses
Modern physics with lab	1 course
Waves and optics	0-1 courses
Classical mechanics	1 course
Electromagnetism	1 course
Quantum mechanics	1 course
Statistical mechanics and thermodynamics	0-1 courses
Advanced laboratory	1-2 courses
Electronics	0-1 courses

f. Particular characteristics of American University

In addition to comparison to other colleges and universities, it was also important to identify particular characteristics of AU that would affect the physics program. One important attribute is that AU places a high priority on undergraduate participation in study abroad. Typically, the high number of course requirements and rigid structure of course progression make this difficult for physics majors. A goal for setting a new curriculum included providing enough flexibility for students to have the opportunity to study abroad but enough standardization so that graduates of our program would be prepared comparably to students at other national universities.

Finally, we compared the number of credit hours required for a physics B.S. to the number of credit hours required for B.S. degrees in other programs in AU's College of Arts and Sciences. Results are shown in Table 4. By comparison to other degrees at AU, the physics requirements were near the bottom, indicating the possibility of creating additional course requirements.

Table 4. Requirements for B.S. programs offered at American University

B.S. Program	Major Requirement Credit Hours
Biology	72
Biochemistry	72
Computer Science	70
Chemistry	69
Applied Mathematics	57
Multimedia Design and Development	55
Applied Statistics	54 or 55
Audio Technology	54
Health Promotion	54
Applied Physics	53
Mathematics	52
Computational Physics	51
Mathematical Statistics	47

g. Particular characteristics of AU's physics program

In addition to peculiarities of the university as a whole, the physics program at AU is structured in a unique way. AU's physics program is integrated within a single department along with two other disciplines in the department of Computer Science, Audio Technology, and Physics (CAP). This structure was considered in devising the new curriculum as an opportunity to combine the strengths of these different but related disciplines.

One way of utilizing this opportunity is in offering courses that would be of benefit to the physics program as well as to computer science or audio technology. With only four full-time physics professors in AU's department, efficiency is required in order to expand course offerings without overburdening the professors. At the time of the evaluation, the audio technology program regularly offered two courses with labs in electronics. In addition, we felt that a waves and optics course offered by the physics department could be of interest to audio technology students. Therefore, by working together with different disciplines within the department, course offerings could be expanded in such a way as to involve different aspects of the department.

We are also taking advantage of the cross-disciplinary nature of our department by requiring all physics majors to take a course in introductory computer science. We include this requirement for several reasons. First, it means that all graduating physics students know sufficient rudimentary programming to model experiments on computers. Second, by exposing physics students to programming, the course has the potential to spark their interest in computational physics. Physics students constitute a significant portion of the enrollment in the introduction to computer science course, and the course is being partially adapted to this audience. These adaptations include recent student projects in modeling a physical system, and plans to teach MATLAB programming as well as Java in future offerings of this course.

h. AU physics student feedback

In addition to the above considerations, student feedback was also sought in determining the course of action for the program. The two most recent graduates from the program were interviewed in making the decision. They were both entering Ph.D. programs in physics the fall following their graduation. Both said they wished that there had been more physics courses offered. In addition, they wished they had been a part of a larger cohort of majors. This input confirmed the goals of increasing the courses available and trying to attract more students to the major.

In addition, we decided to make student input a part of our plan for assessing the changes made to the program. Prior to this assessment, counselors from the College of Arts and Sciences had the responsibility to advise physics students, meaning that the interaction between students and the professors in the department was at times fairly minimal. We sought to change this as well.

III. Changes made to the AU physics program

Based on the assessment of our program and comparison with other programs as summarized in Section II, we identified a plan to reinvigorate the physics program at American University. This plan included changes to the course offerings, requirements, and the advising structure; the establishment of regular goal setting and assessment; and a focus on reorienting the program to make it more attractive to students. These changes are discussed in more detail in subsections below.

a. Changes made to course offerings and requirements

The major points in the changes to the major requirement and course offerings are:

- Create a track in traditional physics. This required the creation of a few new classes and the more frequent offering of others.
- Maintain the tracks in computational and applied physics, but modify them so that more physics is required.
- Broaden curriculum and increase number of credit hours for all tracks to a level more in line with biology, chemistry and computer science at AU and more similar to other colleges and universities.
- Complete the above by utilizing the resources and strengths of the department in a way that maintains flexibility and addresses student preferences and is informed by national trends in undergraduate physics programs.

First, we added a traditional physics track in addition to the computational and applied physics tracks. We established a core curriculum which is required of all physics majors and includes all of the previous physics course requirements while adding waves and optics and quantum mechanics. In addition, each track was expanded and made more comprehensive with the addition of courses and requirements. To do this, two semesters of electronics with laboratory were added as part of the regular curriculum, as well as a semester of quantum mechanics. Each of the tracks was expanded to require between 58 and 61 credit hours to bring them in line with the higher end of the other science programs at AU (*cf.* Table 4).

A six-year plan of course offerings maximizes course offerings by making upper level courses available on a rotating basis. With this plan, introductory courses and modern physics are offered every year, but upper division courses are offered every two years (for instance quantum mechanics is offered in the spring of odd-numbered years and statistical mechanics is offered in the fall of even-numbered years). In this fashion, all majors are able to take each upper division course either in their junior or senior year, depending on their cohort. In addition, one semester every two years was identified as a semester where students can participate in study abroad programs without preventing them from completing their program requirements.

b. Student advising done within the department

Simply adding more courses would not necessarily address students' needs. To ensure that these needs were met, the physics professors took over the responsibility of advising physics majors, previously done by counselors from the College of Arts and Sciences. This allows for more interaction between students and professors and improves our ability to ensure student success and to receive feedback from the students.

c. Regular assessment and goal setting

Working with the university, the department is now submitting annual academic outcome reports including goals for the year and reporting progress towards the goal set the previous year. In addition, we have begun a program for interviewing past graduates for feedback regarding their evaluation of their experience at AU and how it prepared them for life after graduation.

d. Reorienting towards student needs

Several of the above changes – including the additional course offerings, student advising and graduate interviews – were made with the goal of being more student-oriented. In addition to this, the physical space of the department has been reorganized to make the building more inviting and student-friendly and to provide space for students to get together outside of class.

IV. Evaluation and conclusions

As this program was enacted in the Fall 2004 semester, we are roughly half-way through the first six-year plan. Thus, it is too early to draw firm conclusions about the success of this program. However, the preliminary data from our evaluations indicates that there has been improvement in the size and quality of the physics undergraduate program.

The first time it was possible to graduate under the new track was in the 2004-2005 academic year. The average number of students graduating with physics majors in the three academic years before the change was two per year. The average number of physics majors graduating in the three years after the change (including students who are on track to graduate in Spring 2007) was six per year. While this is a fairly small sample size, we believe that these results indicate that the program has become much more attractive to potential majors.

In addition, students who matriculated under the old program are able to choose whether to graduate under the old requirements or the new requirements. Of the students who had this choice, six chose to graduate under the old standards, while twelve selected the new program, even though the requirements for graduation are more stringent under the new program. The majority of students graduating since the change have opted for the traditional physics track, indicating that there is a strong desire for a solid grounding in physics and that the addition of this track served a need.

The changes made tend to reflect the desires of students for a more rigorous traditional physics program. This is reflected in responses to our first survey of recent graduates. We sent surveys to all of the students who graduated in the last five years. Note that this includes students who graduated under both the old and the new programs, and since the survey answers were anonymous, this does not allow us to compare responses from the two sets of students separately. However, of the six responses to the question "what courses would you add or delete among those required of a physics major," three students suggested adding quantum mechanics, three students suggested statistical mechanics, and one suggested waves and optics, while another mentioned just optics. Other suggestions included a second semester of electricity and

magnetism, a second semester of statistical mechanics/thermodynamics, and advanced calculus. This indicates that the changes we are making are in a direction responsive to what the students felt was lacking in the program.

There could be some concern that making the program more rigorous and adding additional requirements could drive students away. However, most of our experience has been the opposite. Instituting a more stringent set of requirements has attracted many more students by indicating to them that they will receive a solid grounding in physics and that their degree will prepare them for graduate school in physics or employment after college. Overall, during the time period described by this paper, the physics program at AU has transitioned from a program which had been declining to one that has grown significantly and is becoming a vibrant pole of attraction for students.

The number of undergraduate physics majors and minors at American University continues to grow. Currently we have 18 declared majors and 13 declared minors. Additionally, AU has also been named as one of the 18 physics programs in the U.S. that graduates over 40% women, indicating that our program can play a role in moving towards gender balance that is much needed in physics.[6]

In conclusion, our program has undergone a major re-orientation in its focus and a corresponding adjustment in the options offered to our students. We have thus far seen a positive result, including an expansion in the number of physics majors. The main focus of our changes was in offering flexibility to students by maintaining a three-track system, while emphasizing a rigorous program in physics. We believe that these results show that a desire for solid science education exists even at institutions that (like AU) are not primarily known as science-oriented institutions. For these reasons, the methodology used in making our changes could be useful for other institutions seeking to improve their programs.

Appendix

National Private Universities in the Second Tier used for comparison include Fordham University, Loyola University, Marquette University, Seton Hall University, University of Dayton, University of San Diego, University of San Francisco, University of St. Thomas, University of the Pacific, University of Tulsa, and St. Louis University.

Private Liberal Arts Colleges in the First and Second Tier used for comparison include Swarthmore College, Williams College, Wellesley College, Carleton College, Bowdoin College, Middlebury College, Grinnel College, Reed College , Oberlin College, Colgate University, and Bucknell University.

Bibliography

[1] Patrick J. Mulvey and Starr Nicholson. *Enrollments and Degrees Report, 2004*. AIP Statistical Research Center, 2004.
[2] R.C. Hilborn, R.H. Howes, and K.S. Krane. *Strategic Programs for Innovations in Undergraduate Physics: Project Report.* The American Association of Physics Teachers, College Park, 2003.
[3] Rachel Ivey and Katie Stowe, *Physics Bachelor's with Master's Degrees.* AIP Statistical Research Center, 2003.

[4] Rachel Ivey and Katie Stowe, *The Early Careers of Physics Bachelors*. AIP Statistical Research Center, 2002.
[5] America's Best Colleges 2002. *U.S. News & World Report*, (2002).
[6] Rachel Ivey and Kim Nies Ray, *Women in Physics and Astronomy, 2005.* AIP Statistical Research Center, 2005.