Paradigms in Physics
Revising the Upper-Division Curriculum

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Introduction

Paradigms in Physics is a project at Oregon State University to revise the entire upper-division curriculum for physics and engineering physics majors to make our program more modern, integrated, and flexible and to increase students' success.

The Old Curriculum

Pressure on the old curriculum came from a number of sources. Our students had ever more diverse educational goals: about 2/3 of our majors were physics majors and 1/3 engineering physics majors—both groups contained increasing numbers of students who were industry-bound rather than graduate-school bound immediately after graduation, others of our majors had interdisciplinary interests such as geophysics, computational physics, and mathematical physics. More generally, our curriculum hadn't been comprehensively updated in decades and was in need of an overhaul, including more modern topics.

Our old curriculum, full of year-long sequences of courses in the traditional physics subjects, was characterized by rigid scheduling that made choices difficult. Each subject area was treated in a single year, so that the junior-year sequences were roughly the same level of difficulty as the senior-year courses. Since it was difficult to revisit topics, it was also difficult to highlight many of the beautiful interrelationships across disciplines.

Changes

In our new curriculum we chose to change practically everything. Our first concern was to optimize the arrangement and update the content of our courses. Then we chose an unusual schedule for the junior year. Instead of having students take 2-3 courses at a time, three hours per week, over an entire term, we chose, instead, intensive courses meeting 7 hours per week (MWF for 1 hour each, TTh for 2 hours each) for just three weeks. Students take only one course at a time, so they can focus their attention on a single topic. The longer blocks of time on Tuesdays and Thursdays allow us to experiment with innovative pedagogical techniques, which can not be accommodated in an ordinary one hour block. We also chose to address explicitly many hidden curriculum topics, such as the development of our students toward practicing professionals, which had only been addressed haphazardly and implicitly in our old curriculum.

What Are Paradigms?

We call the new junior-year courses Paradigms. Each paradigm covers a conceptual example of physics, such as harmonic oscillations, in a way that spans two or more of the traditional physics disciplines. Many Paradigms were chosen, for example, to have both a quantum and classical base. Each Paradigm is designed to help students develop

explicit problem-solving skills. We chose the pedagogical strategies for each Paradigm appropriately for the content and hidden curriculum goals of each course.

The Paradigms courses that we currently teach are:

- Symmetries & Idealizations
- Static Vector Fields
- Oscillations
- 1-D Waves
- Spin & Quantum Measurements
- Central Forces
- Energy & Entropy
- Periodic Systems
- Rigid Bodies
- Reference Frames

What Are Capstones?

The Paradigms courses are followed, in the senior year, by a number of more traditionally delivered, one-quarter-long courses in the usual disciplines of physics:

- Classical Mechanics
- Mathematical Methods
- Electromagnetism
- Optics
- Quantum Mechanics
- Thermal and Statistical Physics

These courses, which we call Capstones, have a more condensed format than traditional courses with the same titles, since they build on the concepts developed in the Paradigms.

We are also able to offer a selection of specialty courses adapted to the particular interests of our faculty and students.

- Electronics (required of all physics majors)
- Independent Research and Thesis (required of all physics majors)
- Solid State Physics
- Nuclear & Particle Physics
- Computational Physics
- Atomic, Molecular, & Optical Physics

Pedagogy

The structure of the Paradigms and Capstone courses alone has helped us achieve a much greater degree of flexibility than in our old curriculum. By chopping the content up into smaller pieces, calling the pieces by their names (e.g. Central Forces instead of Quantum Mechanics), and listing them in the course catalogue as separate courses with their own course numbers, we have established a system which allows students with interdisciplinary interests or from other departments to choose (with the help and approval of an advisor!) those courses which are most appropriate to their career goals.

The pedagogical strategies in the Paradigms curriculum were chosen to encourage both collaborative and independent learning. We have incorporated a wide variety of student-

centered activities including: small group activities, integrated laboratories, projects, learning cycles, journal research, and computer-aided visualization activities.
We have found that these active-engagement strategies are effective, but very slow. As such, we consider them a precious commodity that must be used wisely. While the structures of some of our activities parallel those that have been employed successfully at the lower-division level, some are unique to the special needs of the upper-division.

Early Problems and Successes

Not unexpectedly, the first years of the program were too much work for the faculty. The students also described a workload that was too heavy, but interestingly, the cause was not the total workload so much as the lack of weekly rhythm in the classes. Homework and project due dates changed when the courses changed—every three weeks, making it difficult for students to juggle their studies with their personal/family/work lives. The simple expedient of imposing an artificial weekly rhythm of Wednesday and Friday due dates on all Paradigms did much to resolve this early problem.

We use standard textbooks for most of the Paradigms, covering, for example, chapters 2 and 5 from one book with chapter 6 of another, all within a single course. Remarkably, students are not fazed by the changes of notation inherent in this procedure, but rather come to see notation changes as something that a professional must take in stride. It is not unusual to see a student in our study room with several books open at once. Several other early problems have arisen; none are unmanageable.

Already in the first years of the program, we are seeing a number of successes: The external evaluation team concludes that student learning is different, but not less. In particular, students are using a greater variety of problem-solving tools, their visualization skills have improved, and some of the at-risk students are staying in the program long enough to be successful. Problems that baseline students in the old curriculum had with a variety of notations disappear in the new curriculum. Some content, such as thermodynamics, is more accessible to the students.

Everyone involved benefits in some way from the experience: student camaraderie is enhanced and faculty are enthusiastic. Several Teaching Assistants have commented that they wish their own undergraduate curriculum had been taught in this way.

The division of content into cross-disciplinary topics, taught in intensive three-week modules, is judged by the faculty to be more successful than we expected. A number of students have remarked that they found the cross-disciplinary approach motivating. They also like being able to focus on a single topic at a time; the daily schedule keeps some students from forgetting what they were working on from one class to the next.

Current Focus

As we enter our fifth year of the new curriculum, our primary focus has evolved beyond the initial development of materials. We are currently engaged in defining and articulating what makes the Paradigms curriculum special, as an initial step in the process of institutionalizing the program at Oregon State University and in disseminating the ideas and materials elsewhere. Our external evaluation team is developing profiles that detail the successes of our curriculum as well as the problem spots. By rotating the courses amongst our own faculty, we are discovering what types of materials are necessary to put in other faculty members' hands for them to be comfortable using them in the classroom, adding-to and modifying our materials accordingly.

Unfortunately, the content of our new curriculum has been so radically rearranged that an institution that hopes to follow our model, would need to undergo the same kind of wholesale change we did. We are well aware of how difficult this is! We completely developed 15 new courses in just two years. To alleviate this situation, we are attempting to develop gentle adoption plans that would first allow institutions to use smaller portions of our materials in existing courses and practice with student-centered pedagogies at the upper-division level, before making a decision to adapt or adopt the new curriculum to their setting. This strategy should also allow us to further test our materials at diverse institutions and refine them appropriately.

Acknowledgements

This material is based upon work supported by the National Science Foundation under Grants No. DUE 96-53250 and DUE-0088901. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation. The project has also received support from the Department of Physics, College of Science, and Academic Affairs at Oregon State University and the Hutchcroft Fund at Mount Holyoke College.