Upper-Level Physics: Curricular Issues

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What is Upper-Level Physics?

- Beyond introductory classical and modern
- Usually junior/senior years of undergraduate
- Curriculum leading (mainly) to baccalaureate degree in physics or closely related area (such as applied physics, engineering physics, etc.)
- Focus on physics, but applies equally to astronomy
- Could easily map onto graduate courses

What are the three most important goals of your department’s upper-level physics or astronomy program?

List in order of importance (1 = most important)

What fraction of your physics/astronomy baccalaureates go on to grad school in physics or astronomy?

<10%	
10-30%	
30-50%	
50-70%	
>70%	

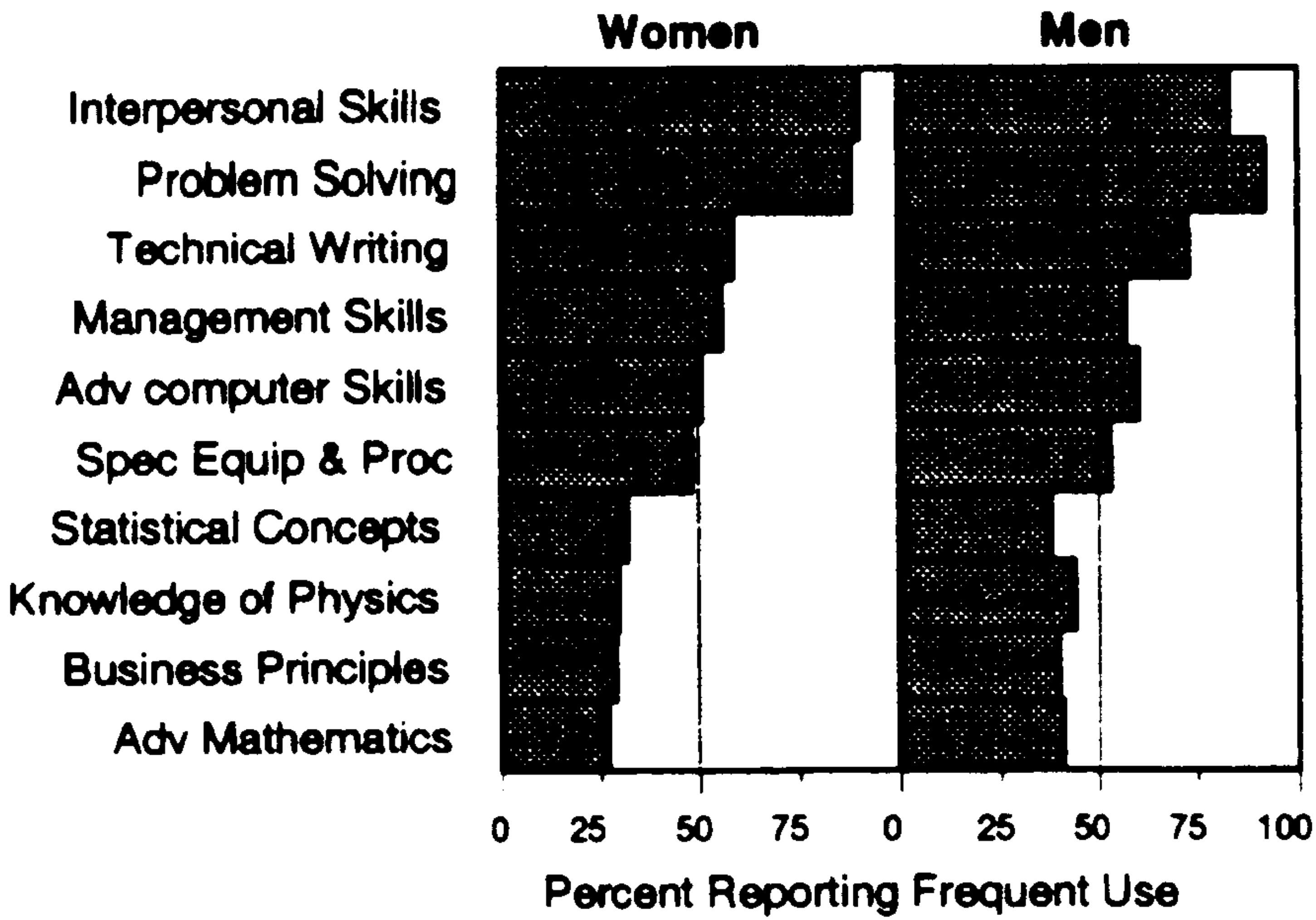
What fraction of U.S. physics & astronomy baccalaureates go on to graduate school in physics or astronomy?

<10%	
10-30%	
30-50%	
50-70%	
>70%	

If you surveyed the baccalaureates from your institution who joined the technical workforce, in what order do you think they would rank the skills they require for their employment?
(1 = most important)

- Knowledge of physics
- Knowledge of statistics
- Familiarity with specialized equipment and processes
- Advanced computer skills
- Management skills
- Technical writing
- Problem solving
- Interpersonal skills

Figure 1. Skills Used Frequently in the Workplace, by Gender.



What Have You Learned Thus Far From Eric Mazur, Lillian McDermott, Ed Prather?

- Students learn by thinking and doing, not just by watching
- What we say is not always what they hear
- Multiple representations are often important
- Many students can learn to solve traditional problems without gaining true understanding
- Your teaching should have the same systematic approach as your research
- Teaching physics involves a continuous learning experience for the instructor

How can we apply these principles to upper-level courses?

Components of Upper-level Physics Programs

Total physics credits (intro plus upper) required as a percent of total credits needed to earn a bachelor's degree by "standard" physics program

Standard physics degree program	Typical range of percent of physics credits		Number of Respondents
	Low	High	
Bachelor of Science in physics	27%	41%	413
Bachelor of Arts in physics	23%	37%	100
Other bachelor's program	22%	40%	32

For example, if your school requires 120 semester credits for a B.S. degree, then a typical range of required physics credits would be from 32 (27% of 120) to 49 (41% of 120)

Typical range includes 10^{th} to 90^{th} percentiles. 10% of respondents have values below the low value and 10% have values above the high va lue.

Specific courses required in "standard" physics degree program

	Standard physics degree program Bachelor of Science %	Bachelor of Arts %	Other Bachelor %	Overall %
Introductory classical physics	99	99	97	99
Intermediate classical mechanics	97	88	87	95
Introductory modern physics	95	94	94	95
Intermediate electromagnetism	96	88	81	94
Advanced laboratory courses	90	74	90	87
Quantum mechanics	88	74	65	84
Thermal and/or statistical physics	82	57	81	78
Mathematical physics	45	38	36	43
Optics	46	24	52	42
Other physics courses	85	82	87	84
Number of Responding Departments	387	92	31	510

Credits in specific courses as a percent of the total physics credits in the "standard" degree program

	Standard physics degree program		
	Bachelor of Science %	Bachelor of Arts %	Other Bachelor %
Introductory classical physics	22	24	26
Advanced laboratory courses	12	13	14
Intermediate electromagnetism	11	11	10
Introductory modern physics	10	12	11
Intermediate classical mechanics	10	11	10
Quantum mechanics	10	11	8
Mathematical physics	8	11	9
Thermal and/or statistical physics	8	10	9
Optics	8	10	9
Other physics courses	18	20	19
Number of Responding Departments	380	91	30

Working Model of Upper-Level Physics

(excluding laboratory courses)

- Classical mechanics
- Electromagnetism
- Quantum mechanics
- Thermal & statistical
- Mathematical methods

Largely unchanged in past 50 years:

- Content
- Understanding of how students learn
- Teaching methods

Properties of Traditional Upper-Level Curriculum

- Long sequences
- Little opportunity to revisit concepts in same or different contexts
- Rigid scheduling (e.g., no thermo or QM before GRE)
- Separation of subjects
- No explorations of interrelationships of topics
- Step function in difficulty between introductory and upper-level classes
- Tyranny of textbook
- Lack of active engagement, group learning, etc.
- Difficulty of incorporating computational techniques – simulations, visualizations, etc.

What Would be the Characteristics of an Ideal Upper-Level Curriculum?

- Small, bite-sized pieces
- Explore interrelationships of concepts and techniques
- Avoid duplication
- Encourage student interactions
- Encourage faculty interactions
- Gradually increase depth and sophistication over 2 years (ramp vs. wall)
- Spiral approach
- Promote familiarity with different representations (e.g., equations vs. graphical; matrix vs. wave function in QM)
- Promote good pedagogy: active engagement, small group activities, etc.
- Easy to add computational components

Is Your Course Properly Imbedded in its Context?

How do Your Notation and Terminology Compare with Those of:

- Other Upper-Level Physics Courses Students are Taking or Will Take?

  vectors, unit vectors, wave eqn, etc.

- Math Courses?

  div, grad, curl, θ vs. ϕ, unit vectors, etc.

- Introductory Physics Courses?

  potential V vs. potential energy U

Pedagogy

Encourages both collaborative and independent learning:

- Small group activities (whiteboards)
- Kinesthetic activities
- Preflight warm-ups
- Integrated laboratories
- Projects
- Visualization, simulation, animation
- Computation

Does your classroom support and encourage this pedagogy?


Whiteboards

Paradigms in Physics
Oregon State University (since 1996)

- Result of search for common themes in upper-level courses
- 2nd potential minimum
- Junior year: Nine 3-week modules (“paradigms”) taught sequentially
- Seven hours per week (1 hour M/W/F, 2 hours T/Th)
- Independent courses, separate numbers in catalog, separately graded, different faculty
- Faculty collaboration, must adopt content and pedagogy
- Topics re-ordered compared with traditional curriculum (same topics, different order)
- Include 2 or more subdisciplines, often quantum + classical
- Use interactive pedagogy – active engagement, small group problems, etc.
- Extensive use of computational techniques: Maple worksheets, simulations, visualizations
- Senior year: “Capstones” each dealing with a single subdiscipline at an advanced level
- Common set of (traditional) textbooks for junior & senior year (mechanics, e&m, thermo, quantum, math methods)

Paradigms

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

Examples of Paradigms Course Descriptions

1-D waves:

Waves in one dimension, in both classical and quantum systems. Waves in electrical circuits, waves on ropes and the matter waves of quantum mechanics. The basic language to describe waves, standing and traveling waves, wave packets and dispersion. Energy, reflection and transmission, impedance.

Central forces:

Central forces in classical mechanics especially planetary motion, with emphasis on the importance of the conservation of angular momentum and the concept of the effective potential. Separation of variables in Schroedinger's equation and related equations in the presence of spherical symmetry, leading to a study of spherical harmonics and angular momentum operators. Quantum theory of the hydrogen atom.

Reference frames:

Newtonian physics and inertial frames. Physics on a rotating Earth in terms of apparent centrifugal and Coriolis forces due to the use of rotating frames. Extension of the use of multiple frames of reference from the Newtonian framework to Einstein's special theory of relativity. Galilean and Lorentz transformations. Unification of electricity and magnetism provided by special relativity.

Capstones
Senior year, 10 weeks each
More traditional in structure (3 one-hour classes per week)

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

- Optics, electronics, research/thesis, specialty courses (computational, condensed matter, AMO, nuclear/particle)

The Student View

Coming from the paradigms background, I immediately felt comfortable working in a team atmosphere: sharing ideas, problem-solving, double-checking your work with others. The other benefit of the paradigms program I have found was becoming accustomed to the quick turnaround between projects. Since the classes were only three weeks long, you got used to concentrating heavily on one area, then switching focus to another concentration. This, I have found, is exactly what the production environment is like.
—2002 engineer at aerospace company

One of the best things about organizing the classes by paradigm rather than by application was that each concept was applied to different areas of physics in rapid succession. This encouraged me to see each concept as a useful tool rather than as a math trick specialized to a narrow set of problems. Learning this way was extremely exciting and I remember toying with the application of basis functions, vector fields, and canonical ensembles to diverse things like taste, color, economics, and evolution. I learned faster in paradigms than at any other time in college.
—2000 graduate student at Cornell

More Information

- Physics Today, September 2003, p. 53
- American Journal of Physics, v. 69, p. 978 (2001)
- http://physics.oregonstate.edu/portfolioswiki/
- Quantum: Rick Robinett @ Penn State

  Chandralekah Singh @ Univ. of Pittsburg
- E&M, Quantum, Clickers in upper level: Univ. of Colorado Physics Education Group

  http://www.colorado.edu/physics/EducationIssues/index.htm
- www.thequantumexchange.org

Questions?

Undergraduate Research

	Standard physics degree program Bachelor of Science %	 Bachelor of Arts %	 Other Bachelor %	Overall %
Research experience	36	29	37	35
Thesis	14	19	17	15
Number of Responding Departments	421	103	35	559

Undergraduate Research

- Why is it important?
- How to include UGs in research?
  - Summers vs. academic year
  - Special projects vs. regular research
  - Experiment vs. theory vs. computation
- Resources
  - REU, RUI (NSF)
  - Council on Undergraduate Research
  - Journal of Undergraduate Research in Physics
  - American Journal of Physics
  - The Nucleus
  - Problems and pitfalls