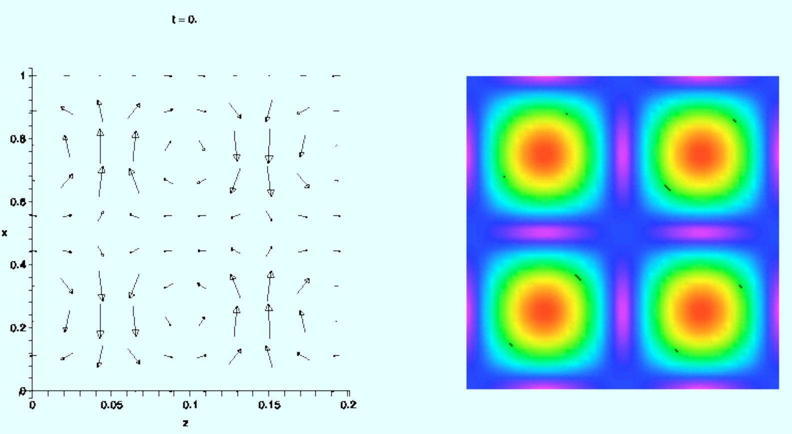
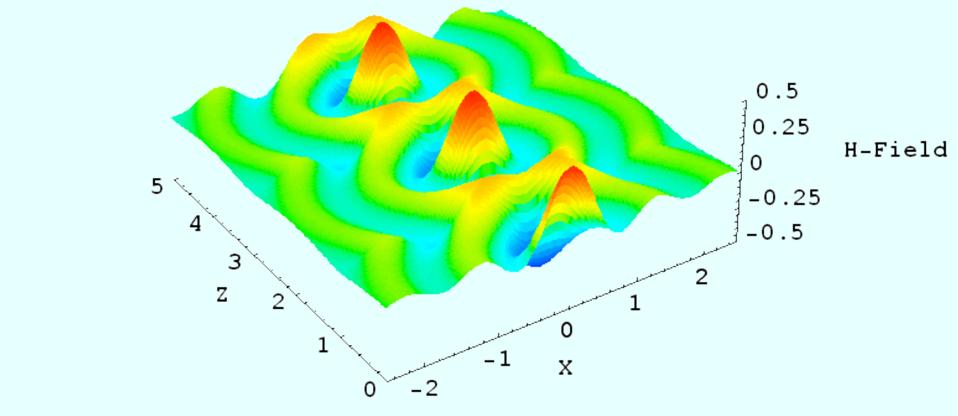
COMPUTATION IN THE PARADIGMS CURRICULUM at OREGON STATE UNIVERSITY

PARADIGMS IN PHYSICS



Student class work showing TE_{21} mode in EM waveguide

The Paradigms in Physics Project at Oregon State University has reformed the entire upper-division physics curriculum. This has involved both a rearrangement of content to better reflect the way professional physicists think about the field and also the use of a number of reform pedagogies that place responsibility for learning more firmly in the hands of the students. A variety of computational examples and exercises are used throughout the courses. Our students are comfortable with computational techniques and tools since they take a required introductory computational physics course that also acts as a gateway for our Computational Physics degree program. We use Maple, Mathematica, Java, and other software packages to help students do calculations, visualize graphics, and perform simulations.



Student thesis work showing EM wave in negative index material

The Development Team

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PARADIGMS CURRICULUM

Paradigms (P) & Capstones (C)

The junior year consists of short case studies of paradigmatic physical situations which span two or more traditional subdisciplines of physics. Most have both a classical and quantum base. They are designed explicitly to help students gradually develop problem-solving skills. The senior year consists of more conventional single-quarter lecture classes in each of the traditional subdisciplines of physics. The format is more condensed than in the old, traditional curriculum because the content builds on the examples of the paradigms in the junior year. An overview of our curriculum is shown at right.

Fr		•Intro Computational Physics	
So			
Jr P	•Symmetries & Idealizations •Static Vector Fields •Oscillations	•1-D Waves •Spin & Quantum Measurements •Central Forces	•Energy & Entropy •Periodic Systems •Rigid Bodies / Reference Frames •Class Mech (C)
Sr C	•Math Methods •E & M	•Quantum Mechanics •Thermal Physics •Optics	

Computational Physics BS

Since 2003, we have had a program in Computational Physics for UnderGraduates (CPUG). This BS degree is supported by 5 courses, including a freshman level introductory course that all our physics majors also take. This early introduction provides a solid basis for the additional computational aspects of the Paradigms curriculum.

More information about CPUG:

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- www.physics.oregonstate.edu/CPUG

COMPUTATIONAL TOOLS AND ACTIVITIES

Computational Approach

Throughout the Paradigms curriculum, we use a wide variety of computational activities that employ a broad range of tools. We start using computation early in the curriculum and make frequent use of computation in order to breed familiarity and build student confidence. By the end of their degrees, our students are very comfortable with using computation to help them learn physics. This is one of the many ways in which we strive to teach our students to think like professional physicists.

Computational Activities

- Visualization
- Animation
- Calculation: Symbolic & Numerical
- Multiple representations
- Simulations, "experiments"

Computational Tools

- Maple
- Mathematica
- MathCAD
- Java
- Excel
- Labview
- CUPS
- SPINS (Java)
- OSP, EJS
- Wien2K

EXAMPLES

Effective Computational Activities

We have experimented with many types and styles of computational activities and have identified several issues that are important in designing effective activities.

- Transparency: How much of the coding is presented to the students, and how much is hidden?
- Control: Who controls the direction of the activity, the student or the instructor?
- Wow factor: Does the activity simply wow the student with pretty pictures?
- Length: Can the activity be completed in class?
- Topics: Does the activity address one issue or many? Does it bring up unintended questions or issues?

Fourier Activities

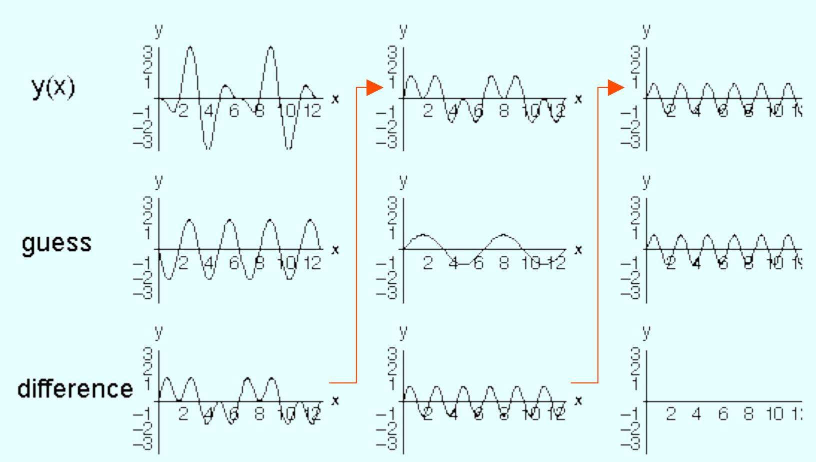
Fourier analysis is integral to several of the Paradigms courses, and we use many computational activities to enhance student learning.

Activity	Tool	Outcome
• Guess coefficients	• Maple	• Intuition
• Calculate coefficients (paper & comp)	• Paper, Maple	• Mathematics
• Transform impulse response	• Excel FFT	• Dual Spaces: ω-t
• Periodic system mode frequencies	• CUPS FFT	• Normal Modes
• FFT experiments	• Labview	• Aliasing,leakage

The plots shown below are from a Maple activity where students are asked to guess the Fourier coefficients of a simple linear combination of sine functions. It is designed to develop students' Fourier intuition and also to make sure they know how to add functions pointwise.

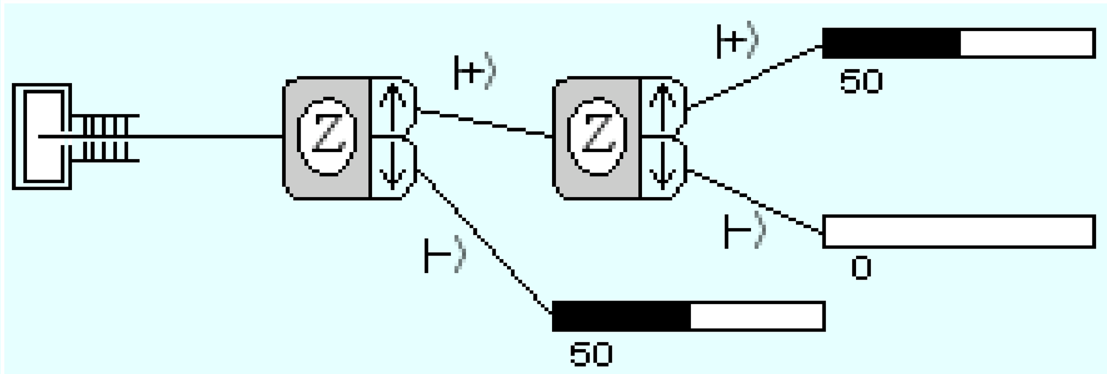
Maple coding:
$y(x) = 4\sin x\left(1-\cos x\right) - 4\sin^3 x$

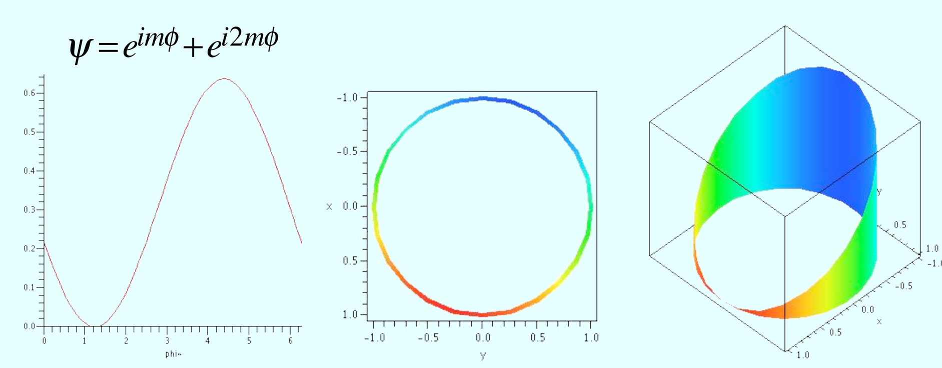
Fourier series:
$y(x) = \sin x - 2\sin 2x + \sin 3x$



Quantum Mechanics through Spin

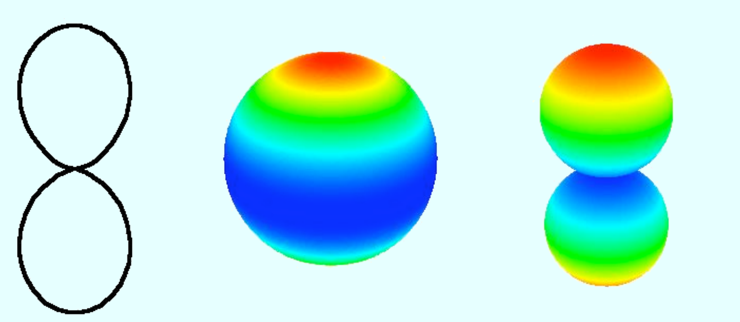
Our rearrangement of content allows students to begin their exploration of quantum mechanics earlier, in the middle of the junior year. We take a spins-first approach and use a computer simulation of Stern-Gerlach experiments throughout the students' introduction to quantum mechanics. We ported the original Pascal software (Schroeder & Moore, Am. J. Phys. **61**, 798-805, 1993) to Java and it has since been incorporated into Open Source Physics. The SPINS software allows students to simulate successive Stern-Gerlach measurements and explore issues such as incompatible observables, eigenstate expansions, interference, and quantum dynamics. The program has several unknown quantum states that the students must determine from measurements. Traditional curricula approach these problems backwards: predicting the results of experiment from knowing the quantum state. The screen shot below shows successive S_z measurements.



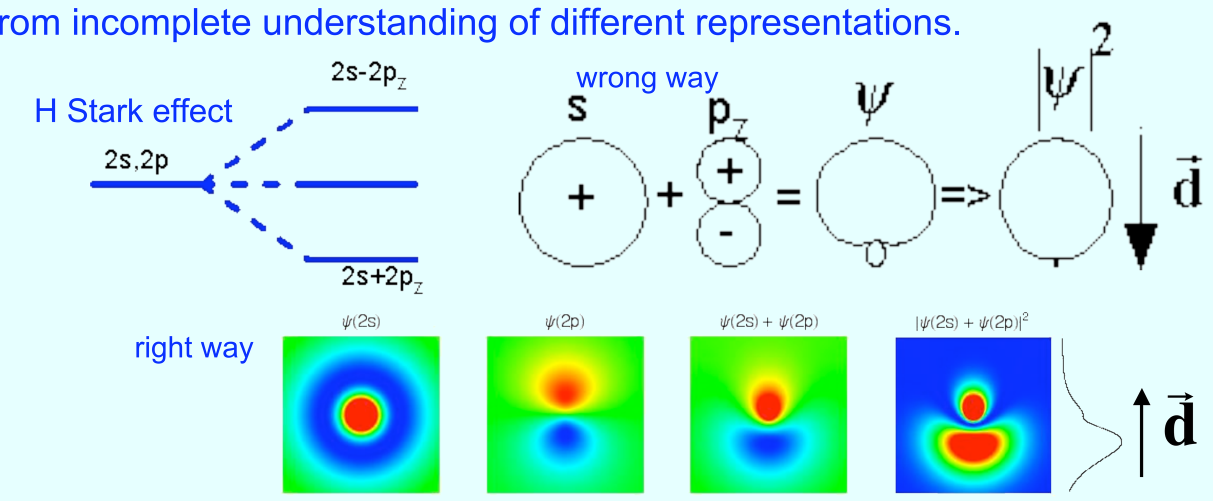


Multiple Representations

Professional physicists are comfortable with a wide range of representations of physical quantities (pictorial, graphical, algebraic, words, etc.). Students can easily be overwhelmed by the multiple representations presented to them, but we have found that consistent and frequent use of multiple representations can be effective in guiding students' professional development. The plots above show multiple graphical representations of the probability density of a particle confined to a one-dimensional ring. We use this as the first step in developing the ideas of angular momentum eigenstates. We continue to use color as a way of developing student intuition of spherical harmonics, as shown below. The Stark shift in the hydrogen n = 2 states demonstrates the problems that can arise from incomplete understanding of different representations.



$Y_{10}(\theta,\phi)$ polar plot, color plot, and combined plot



REFERENCES

Websites

http://www.physics.oregonstate.edu/paradigms
http://www.physics.oregonstate.edu/portfolios
http://www.physics.oregonstate.edu/CPUG

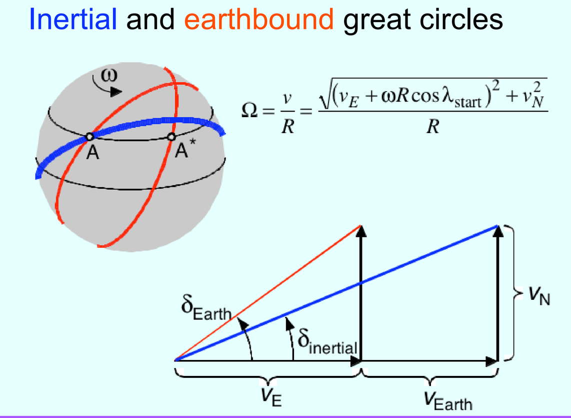
These sites contain:

1. an introduction and overview of the project for the interested public.
2. information for institutions interested in adopting our curriculum or developing new upper-division curricula of their own, including information about workshops, links to publications, detailed syllabi for the new courses, and descriptions of individual activities.
3. detailed materials for many of the new courses, primarily for the use of students at our own university.

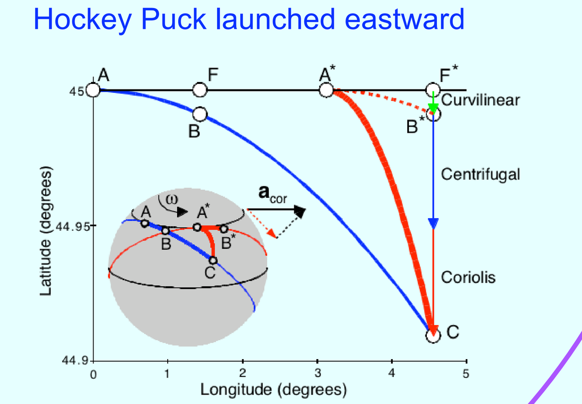
Publications

1. C. A. Manogue and K. S. Krane, *The Oregon State University Paradigms Project: Re-envisioning the Upper Level*, Physics Today **56**, 53-58 (2003).
2. C. A. Manogue, P. J. Siemens, J. Tate, and K. Browne (Department of Physics) & M. L. Niess and A. J. Wolfer (Department of Science and Mathematics Education), *Paradigms in Physics: A New Upper-Division Curriculum*, American Journal of Physics **69**, 978-990 (2001).
3. C. A. Manogue, K. Browne, T. Dray, and B. Edwards, *Why is Ampere's law so hard? A look at middle-division physics*, American Journal of Physics, **74**, 344-350 (2006).
4. D. H. McIntyre, *Using Great Circles to Understand Motion on a Rotating Sphere*, American Journal of Physics, **68**, 1097-1105 (2000).

Inertial and earthbound great circles



Hockey Puck launched eastward



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