Studio Calc/Phys: Combining Physics, Calculus and Active Learning

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Outline

• **Overview** of class structure
• **Why** combine calculus and physics?
• **How?** Reorder the calculus topics/ design activities
• **Goals/means/assessment**
• **Challenges**
Overview of Class

• 24 students in 1998-1999
• 50 students in 1999-2000
• Regular course has 150 students; standard lecture course
• The physics leads the math
• Use standard textbooks plus our own worksheets and UW Tutorials
• For first semester freshman, some of whom have had no calculus.
What is the meaning of “Studio”? 

- What is the studio format? This format, pioneered at RPI [Wilson, 1994], is loosely defined. For us it implies
  - students working in groups on discovery-based, interactive engagement, research-based materials
  - integrating lab into the class
  - far less emphasis on lecture as a mode of imparting knowledge
- Why use this format? There is both theory [Fosnot 96, Redish94, Mestre94] and experiment [Hake98, Redish97] which indicate that students learn better if they are active participants in the process.
Why combine calculus and physics into one course?

- Transference never “just happens” [Dufresne95]. In particular students do not see how calculus applies to other courses unless it is explicitly used in those courses. (See student comments at the end.)
- Physics context motivates the need for calculus.
- Calculus allows us to move away from special cases (e.g. constant acceleration equations) to general cases (e.g. velocity is the anti-derivative of acceleration)
- We can present both calculus and physics as coherent subjects which study change and use ideas of superposition.
How did we combine them?

• In order to make the calculus and physics mesh, we reordered the calculus topics:
  – We cover many calculus topics in the first month, but only with polynomial functions. The topics we cover include functions, graphs, average rates of change, instantaneous rates of change, derivatives, anti-derivatives. Students are now better equipped to see, for example, that the constant acceleration equations as a specific case of a general procedure because they can derive those equations.
  – We introduce other functions as they are introduced by the physics: logs and exponentials to talk about motion with a drag force; trigonometric functions when talking about rotational motion.
There are several places in the year long course where the courses are tightly connected:

- Kinematics is paired with polynomial functions, average and instantaneous rates of change, derivatives and anti-derivatives.
- Drag force and terminal speed is paired with logarithms and slope fields in calculus.
- Center of mass, moment of inertia and work are paired with Riemann sums and integrals.
- Rotations, oscillations and waves are paired with trigonometric functions.
- Gauss Law is paired with flux through a surface.
- Motion of a comet heading toward the earth and a physical pendulum are paired with Euler’s method for solving differential equations.
- RC circuits, electric fields and electric potential are paired with integration methods.
- Taylor expansions are used to check answers in limits and to solve differential equations.
- Fourier series are paired with waves.
Sample Activity

– Center of mass calculations:
  • Begin with intuitions about balance points
  • Use superposition to find balance point for complex objects
  • Formalize superposition with Riemann sums
  • Integrate to find the center of mass for a rod with non-uniform density.
Technical Details:

<table>
<thead>
<tr>
<th>Monday</th>
<th>Tuesday</th>
<th>Wednesday</th>
<th>Thursday</th>
<th>Friday</th>
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<tbody>
<tr>
<td>Physics</td>
<td>Calculus</td>
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<td>Calculus</td>
<td>Joint meeting</td>
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- Students receive a separate grade for calculus and physics. They can fail one class and pass another.
- We recruit freshmen in Physics, Electrical Engineering, Mathematics, and Honors program since this fits in best with each department program. But we feel all students can benefit from this course.
Goals for the Course and Project

• Improve students’ problem solving ability. Good problem solvers should [Heller92]
  – use appropriate visual representations for the problem,
  – use conceptual knowledge to guide their reading of the problem and problem solving strategy,
  – be able to plan and justify a solution,
  – carefully execute the solution, and
  – check their solution in several ways.

• In service to problem solving, the sub goals are as follows:
  – Develop procedural skills (e.g., taking derivatives, adding vectors)
  – Deepen conceptual understanding
  – Develop strong links between calculus and physics.

• Improve students’ capabilities as independent learners.
Assessment

• Compared our students to students in the lecture course.
• Needed to correct for differences in populations because we had a larger percentage of honors students (our students were not picked at random)
• There is evidence [Cummings 99] that the observed improvement is not due to class size alone.
Corrections

• Statistically correct method
  – Use Kruskal-Wallis analysis to check for presence of statistically significant differences
  – If present, check if difference is due to differences in background, using analysis of covariance

• Intuitive method:
  – Break students into three groups (low/medium/high) based on Math SAT scores and compare these groups across classes.
Goal 1: Develop procedural skills

• Means to this goal:
  – Lots of standard problem solving

• Assessment:
  – Our students did significantly better on 3 out of 4 standard physics and calculus problems
Goal 2: Deepen conceptual understanding

• **Means:**
  – University of Washington Tutorials
  – Conceptual questions on homework, tests, and in-class activities

• **Assessment**
  – FCI % gains: our class 42% gain; lecture course 28% gain
  – E&M assessment in progress
Goal 3: Make clear the connections between Calculus and Physics

• Means:
  – Draw connections whenever possible; reorder calculus to make those connections
  – Have a combined class on Friday where the connections are explicit

• Assessment:
  – Student comments (see next few slides)
  – Our students outperformed lecture-students on a non-constant acceleration problem.
  – More interviews in progress...
Student Reflections on the Course
(These come from anonymous student evaluations of the course.)
They do see the connections very clearly!

– When asked whether this course has been valuable, I think I would be doing the world a great injustice if I were to say no. Physics and Calculus are almost one in [sic] the same. There are so many similarities inherent in these subjects, it seems odd that one would even consider not trying to combine the two. By playing each subject off the other, there are countless perspectives which are found which would otherwise go unnoticed.

– All in all, this course has been very valuable to me. I had taken both physics and calculus in high school, but it is almost as if I was taking completely new courses. There was never any connections made between the two to me in the past, and now that I see them and know how to derive the formulas, I will always know them..
– I took a calculus and a physics course in high school, but this class gives me a whole different view of both those subjects. I could never really make the connection between the two even though I knew they were related in some way. In physics last year we were just given equations and all we had to do was to rearrange them and put numbers in. In this class I actually learn where the equations were coming from and how to derive some of them.

– This course has been extremely valuable to me. I really feel confident in all of the information I have learned throughout the year and I think that being able to apply the two subjects together will make it much easier to retain what I have learned.
Further Assessment on linking calculus and physics

• We used the MPEX (Maryland Physics Expectations) Survey [Redish 1998] to explore student attitudes about physics and learning physics.
  – Last year we administered a simultaneous pre and post test by asking what they believe now and what they remember believing at the beginning of the year. This is not the standard way, but was a measure of students’ perceptions of how they had changed. We saw increases toward the expert view in all clusters, and the largest increases in the math cluster - students felt they were seeing mathematics as more than manipulation and memorization.
  – This year we are administering the test in the standard way.
Goal 4: Problem Solving Skills

• Means:
  – Context rich, real life problems [Heller 92]
  – Use of explicit problem solving strategy for both students and problems done at the board

• Assessment:
  – Interviews and pre and post tests using context rich problems - still in progress.
  – Longitudinal studies in progress
Goal 5: Creating Independent Learners

• Means:
  – Workbooks where students are encouraged to reflect, summarize, apply, connect, ...

• Assessment:
  – Student self-assessment at the end of the course.
Challenges

• All the usual challenges of teaching calculus and physics, plus
• Teaching in “uncharted” territory (i.e. no work on misconceptions, etc.) such as Newton’s method, slope fields, Taylor expansions.
• Constant communication is necessary
  – Email
  – Weekly meetings
  – Phone calls
Is it scaleable?

• See NCSU’s SCALE-UP project for the scalability of active learning environments
  http://www2.ncsu.edu/ncsu/pams/physics/Physics_Ed/

• There are scheduling problems with offering such a course to all students
  – Some students fail one part or the other
  – Transfer students come in with one or other
  – AP credit for calculus
References