Studio Physics at UNH
Rethinking introductory science/mathematics courses
November 2001

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Outline

• What is studio calc/phys?
• Why did we start this project?
• When? a short history of studio calc/phys at UNH
• Where? The newly renovated Kingsbury 311
• Who? what students take this course and who teaches it?
• How did we implement the changes?
• Is it working?
• What does the future hold?
What is studio format?

- Pioneered at RPI, a variant is also being developed at NCSU where their studio classes have 54-99 students.
- Less lecturing, more hands-on, minds-on activities
- Group work
- Lab is an integral part of class
- Use of education research-based materials
- Must meet fewer hours per week in order to be financially viable. (Studio meets 4-5 hours each week; regular physics is 3 lecture hours, 3 lab hours, 1.5 recitation hours; regular calculus is 3 lecture hours, 2 recitation hours.)
Integration of Calculus and physics

• The content of this course is almost the same as Physics 407/408; Math 425/426 (introductory physics and calculus).

• The ordering of topics and choice of applications and projects enhances connections between the two subjects.
### Hours, grades

<table>
<thead>
<tr>
<th>Mon</th>
<th>Tues</th>
<th>Wed</th>
<th>Thurs</th>
<th>Friday</th>
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<tbody>
<tr>
<td>2 hours</td>
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<tr>
<td>Physics</td>
<td>Calc</td>
<td>Physics</td>
<td>Calc</td>
<td>Mixed</td>
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2 grades
2 classes from the registrars point of view.
Can fail one class and pass the other
Why did we begin this project?

• What would you like to improve about the introductory courses you teach?
• What skills would you like your students to have when they begin their sophomore year?
Motivation for studio format

Why the lecture format with 100+ students is not fun:

- You lecture to sea of unengaged faces
- Most (90%) of your interactions with students focus on administrivia instead of physics
- Much of what you say does not stick with them
- No time for Q&A in class.

And this is just how we feel! Imagine how the students feel!
Motivation for combining calculus and physics

- Students don’t have the mathematics background to work with the fundamental physics equations (e.g. velocity is the integral of acceleration) and instead must sometimes work with specialized equations (e.g. constant acceleration equations). Often students are unaware of the very limited applicability of these equations.
- Students don’t see the purpose of calculus when it is taught in isolation, their motivation is therefore low.
- Students don’t see the connections unless they are explicitly made.
- Students often see mathematics as a string of symbols instead of being able to see meaningful patterns of those symbols.
### History of Studio Physics at UNH

<table>
<thead>
<tr>
<th>Year</th>
<th>Description</th>
<th>Funding</th>
<th>Professors</th>
<th>Students</th>
<th>Room</th>
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<tr>
<td>Spring 1998</td>
<td>Studio physics</td>
<td>Yes Small NSF grant&lt;sup&gt;1&lt;/sup&gt;</td>
<td>Leuchnter, Meredith</td>
<td>25</td>
<td>Dem 103</td>
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<td>98-99</td>
<td>Studio Calc/Physics</td>
<td>Yes NSF Grant&lt;sup&gt;2&lt;/sup&gt;</td>
<td>Black, Meredith</td>
<td>23</td>
<td>Dem 101/103 Math room in Morse</td>
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<tr>
<td>99-00</td>
<td>Studio Calc/Physics</td>
<td>Yes NSF Grant&lt;sup&gt;2&lt;/sup&gt;</td>
<td>Leuschner, Black Kraut, and Meredith</td>
<td>47</td>
<td>Dem 101/103 Math room in Morse</td>
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<tr>
<td>00-01</td>
<td>Studio Calc/Physics</td>
<td>No</td>
<td>Meredith, Ryan, and Kraut</td>
<td>50</td>
<td>Dem 101/103 Math room in Morse, Pettee 114</td>
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<td>01-02</td>
<td>Studio Calc/Physics</td>
<td>Fund for the Improvement of Post-Secondary Education&lt;sup&gt;3&lt;/sup&gt;</td>
<td>Ryan, Simpson, Kraut, Zhang</td>
<td>72</td>
<td>Newly renovated Kingsbury 311</td>
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1. Two-year NSF grant for Instrumentation and Laboratory Improvement to write discovery based laboratories. PI - Meredith
2. Two-year NSF grant for Course and Curriculum Development to develop Calculus/Physics Materials. PI’s - Black and Meredith
3. Two-year FIPSE subcontract with NCSU to disseminate their SCALE-UP (student centered activities for large enrollment University Programs) philosophy and materials. PI - Meredith
Typical POD

White Board

Kingsbury 311
fits 12 groups of 3

pallett chairs, storage, coat hooks

computer stand for instructor
Who? Recruitment of students

Who do we recruit and why:

- Physics majors and EE majors (since they must take calculus and physics first semester)
- Honors students (there is no other honors calculus course)
- Math BS majors (it’s good for them!)
- ME majors are encouraged to take the course by their department

However, students who do not fit any of these categories are also in the class.

Therefore, we do not have a random sample of CEPS students. This has implications for interpretation of data.
Who teaches studio?

- For each class there is one physics and one mathematics instructor.
- We have one, if not two Teaching Assistants in the class during group work. Often these are upper division undergraduates.
How did we do it?

- Reordered math content to compliment physics topics
- Made a short list of goals
- Used the education research literature to help us develop strategies to meet those goals
Reordering of Calculus Topics

Regular:

- Study polynomials, trigonometric functions, logs and exponentials as functions (half a semester)
- Derivatives (mid fall semester)
- Integrals (begin at the end of fall semester)

Calculus/Physics (so that students have mathematical tools when needed in physics).

- Polynomials as functions, rates of change, derivatives, antiderivatives within the first month
- Exponentials and logs, rates of change, derivatives, antiderivatives within first two months
- Trigonometric functions rates of change, etc by end of fall.
Short list of goals

• Improvement in complex problem solving skills (gather information, choose a strategy, execute and check). Ability to solve open-ended problems

• Development of a strong foundation of physics and calculus concepts, operations and procedures.

• Building of strong connections between physics and calculus, particularly around the common themes of change and superposition.

• Improved attitudes about learning, science and mathematics.
Difficulties we see in problem solving

• At our worst, we all just hunt for equations without thinking about the problem first. For example, how would you answer:

• There are 26 sheep and 10 cows on a farm. How old is the farmer?
What does the education research tell us and how did that influence our strategies?

- Misconceptions
- Conceptual understanding and transference Group work
- Explicit instruction in problem solving
- Metacognitive issues (thinking about learning)
- Time on task
- Group work
Research: Misconceptions

• Students’ initial knowledge and beliefs and misconceptions must be taken into account to promote learning.
• Lectures do little to change these ideas.
• For example, students come in with the notion that force is proportional to velocity (instead of the force is proportional to acceleration, as Newton tells us). At the end of most traditional courses, they still hold this belief.
Research:

Conceptual understanding

- Conceptual understanding is critical for students to transfer knowledge to new situations.
- For example, two groups of students were taught to hit underwater targets with bows shot by arrows. One group just learned by practice, the other by understanding bending of light. The “understanding” group did much better at hitting the target when it was moved to a new location.
Strategies: Concepts

• Many in class activities focus on developing a conceptual understanding. In particular, we use the *Tutorials in Physics* by Lillian McDermott.
• We often use the “illicit-confront-resolve” strategy to move students to the expert point of view.
• Both tests and homework have conceptual questions. (“You get what you test“)
Problem solving

• Research: Students do not learn complex problem solving without direct instruction.

• Strategies:
  - We use the GOAL format
    • Gather (gather data, get a conceptual understanding of the problem, guesstimate the answer, draw pictures or graphs)
    • Organize (decide how to go about the solution)
    • Analyze (solve the problem)
    • Learn (check the problem, what did you learn from doing the problem?)
  - The professors use this at the board, the students use this on their own. Initially there is a lot of scaffolding.
  - We give lots of open-ended problems and projects.
Time on task

• Research: It takes a great deal of time to become an expert on anything. For example, experts recognize effortlessly many patterns that students take a long time to see.

• Strategy: cut down on the number of topics covered.
Metacogition
(thinking about learning)

- Research: Students need to occasionally think about learning and problem solving.
  - One researcher showed huge increases in Force Concept Inventory Scores (60%) when he focused on metacognition.
  - In problem solving: is what I am doing working? If not, is there another approach?
  - In learning: What bothers me about this idea? Does it contradict what I know?

- Strategy:
  - Have occasional discussions about the learning process. (We could do better here.)
Group work

- Research:
  - Group work is one of the most effective teaching tools - it is a two sigma effect.
  - In groups, students find support, get questions answered, are more likely to get unstuck on their own, answer questions of others.
  - Group work is more than a seating arrangement...

- Strategy: have students work in group in class. Have a single product at least some of the time.
Typical Day in Studio

- Lecture for 10 minutes on the relationship between Electric field (E) and Electric Potential (V).
- Students work for 25 minutes on understanding equipotential lines and the relationship to motion and to E field lines. They work on a UNH-developed worksheet that is entirely conceptual.
- Lecture for 10 minutes to recall what we know about the electric field due to an infinite sheet or cylinder of charge.
- Students work for 25 minutes to calculate V from E for the two above situations by integrating. Then they draw the E field lines and equipotential surfaces.
- Students verify experimentally that their calculated V(x) is correct; 30 minutes.
Is it working?

- Student and professor attitudes
- Building connections between math and physics
- Conceptual Understanding
- Procedural abilities
- Problems solving abilities
Attitudes

• Attendance
• Retention
• Student Comments
• Professor Comments
  • All are positive!
Attendance Data

• Calculus/Physics students - an average of 1 person absent each day out of 25, so a 4% absentee rate. Also, it tends to be a few people who are responsible for over half the absences.

• Regular physics data from Bob Simpson shows attendance is around 70%, with a high of 85% and low of 45%.
Retention Data

<table>
<thead>
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<th>% left in CEPS in Sp01</th>
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<tbody>
<tr>
<td>C/P '98</td>
<td>85%</td>
</tr>
<tr>
<td>CEPS '98</td>
<td>66%</td>
</tr>
<tr>
<td>C/P '99</td>
<td>82%</td>
</tr>
<tr>
<td>CEPS '99</td>
<td>74%</td>
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Need to check honors retention rates ....
Student comments

- All students benefit from the more individual attention to individual difficulties; you can answer questions better if you know the students better. (From the students - 20 out of 30 said that interaction with the instructors was an important part of the class.)
- Students are not bored or left in the dust. (When asked if they recommended the course, no students mentioned boredom or being overwhelmed - though many found it difficult and challenging. All students said yes, they would recommend the course.)
Professor comments

From Mark Leuschner and Jim Ryan who both taught the class

- **Yes it is hard work.** “You can't script the class as well. Wandering from group to group requires you to constantly readjust to the chemistry, dynamics, etc. of each group - this often requires you to develop different teaching strategies for each group.”

- **But the interactions are markedly improved** “I think the closer bond makes for a better learning environment for the students, although I think you have to be careful not to get too close - to the point where they don't respect your "authoritarian role."
Student comments about integration of calculus and physics

- I can manipulate equations, and derive important formulas that people usually only try to memorize.
- Without calculus, you can not learn a fraction of the physics possible.
- I can see equations in different ways, and I can see things others can’t.
- I took both physics and calculus in high school, and I had a very hard time with physics apart from calc....and I know others had the opposite reaction, they understood the calc because it made sense in physical terms.
- By applying differentiation and integration in a practical sense it is easier to understand the why in addition to the how.
Assessment using Exams

Studio exams

• always have at least one “both” questions that requires calculus and physics
• Always have at least 20 points on conceptual questions.
• Many problems are quite similar between regular and studio
Conceptual understanding

- On common conceptual problems studio students do much better than “regular” students
  - third law pair 75% vs 27%
  - direction of induced current, 80% vs 57%
  - Force Concept Inventory 42% vs 28% (this is a national test that measures student understanding of Newton’s laws. It is given twice: before and then after instruction. The score is percent gain - how much of what they needed to learn did they learn?)
Procedural skills

- On common physics exam questions, studio students did as well or better than regular students on 22 out of 23 questions. (Data taken over 3 semesters).
- On all of the common calculus problems our students did as well or better than regular students
Do the students feel prepared for future classes?

When we asked the first two years of studio students (now sophomores and juniors) if studio calc/phys help prepare for later classes, the answers were (30 responding out of about 70 asked):

- 25 said yes; 14 explicitly mentioned help with differential equations, 4 with problem solving, 18 mentioned building strong foundation in calculus and physics.
- Only a CS major said that nothing was of particular help in CS classes.
Problem Solving

Did our students improve on complex problem solving?

From “think-aloud” interviews with our students and regular students, we found that 4/5 of our students and 1/5 of the regular students approached problem solving conceptually. The others were “equation hunting”.

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The problem
Comments from “regular” students

C1: I don’t remember all the equations for this stuff.

C1: I don’t know the equation of acceleration, I can’t remember...

C6: I really don’t remember all the equations from first semester.
Continued...

C6: Yeah, so if I had all the equations in front of me I could just, like...I don’t know, I’d just know how to do it then. But...I don’t really remember how to...because I remember, like, for the tests, like there was, like, five equations and I’d just, like, memorize them and then for every problem I wrote them all down.
Calc/Phys Student response

E4: My first guess is to see how fast it’s [the cart] going when it gets to the bottom. I think I can use conservation of energy to do that. Kinetic energy initial plus potential energy initial equals kinetic energy final plus potential energy final. I’m assuming it’s not moving at the top of the hill...

E4: I think I have an initial direction on where to go.

I: OK. What direction?

E4: Um...down (both laugh) Well, work and energy theorem says, or conservation of work...um, work, um, energy must be conserved. So the total energy that the cart is going to have going into the circle is given by, um, gh, or the height that it falls down.
Does it work just because the class is smaller?

Probably not...

- RPI evidence that performance in studio was changed by what students did in class, not just the size of class.
- Nationwide Force Concept Inventory scores are low even for smaller high school classes.
What next?

• Hopes
• Concerns
Hopes

• Neither Kelly nor Dawn are teaching calc/phys this semester, and two sections are being offered - has studio got a life of its own now?

• This is much more fun to teach.

• There is evidence that the students like this much better - can we use it as a recruitment tool?

• Is it a better use of resources to help our most inexperienced learners become independent learners?
Concerns

• We really need a room in Demeritt because of equipment needs (we need to be close to the lab manager and backup equipment).

• Not every instructor feels comfortable in the studio format. Not every student prefers this either.

• Do we have enough teaching power to continue this? Should we have larger studio classes?