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Dear Instructor:

In this manual we have tried to include all of the material to help you understand how and why we have structured studio calculus/physics the way we have. The intended audience is instructors at UNH and elsewhere who are going to teach this or a similar course. You do not have to read this entire manual straight through. It is meant to be taken it bits and pieces, as questions arise.

This manual includes

- **Overview**
  - Our institutional context
  - Why Combine Calculus and Physics?
  - Course Goals
  - Broad Overview of the course, what is the same, what is different from the standard calculus and physics lecture classes?

- How did we combine calculus and physics?

- How we assessed the effectiveness of our class and how you might assess yours

- Technical issues (when did class meet, how did we keep coordinated, what text did we use, how did we grade, how did we recruit students, what happens on the first day, best furniture, our institutional context, keeping logs)

I. Institutional Context

The University of New Hampshire has about 10,000 undergraduate and 2000 graduate students. Of those undergraduates, about 1200 are in the College of Engineering and Physical Sciences.

Almost all of the students in CEPS must take both calculus and calculus-based physics, although at different times in their career here. Only physics and electrical engineering majors take both Calculus I and Physics I together their first semester here. All other majors are encouraged to take Calculus I first, then take Physics I the next semester. Because Physics majors need to take both Calculus I and Physics I the first semester, Calculus I is a co-requisite for Physics I.
As a result, we are unable to really use calculus in the physics course because the calculus is needed in physics before it is introduced in the math course. For example, in physics we talk about derivatives (velocity and acceleration) within the first week of class, yet these are not introduced for about two months in calculus.

In calculus class, many applications of calculus are used as examples, however the applications are very thin.
II. Why Combine Calculus and Physics?

Calculus instructors often find students wondering “Why do we have to learn this?” By combining calculus with mathematics, students see the use of the calculus immediately.

In physics class, if students do not know the relevant calculus ideas then we must present some ideas either by hand waving or the by keeping to only the simplest cases. For example, there is an algebraic derivation of the constant acceleration equations. However this does not help students understand the general idea that velocity is the derivative of distance and the anti-derivative of acceleration. A result of is that students often use the constant acceleration equations in situations where acceleration is not constant.

In short, the physics gives context to the mathematics and the mathematics allows the students to understand the physics more deeply.

Finally, even for students who take calculus first and then take physics, they are new enough to both subjects that they don’t often appreciate all of the connections that are there. Students will not make the connections unless they are explicitly made. Here is a quote from one of our students:

*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.*

It is our hope that students will begin to see mathematics as a rich language, full of subtlety and meaning, that wonderfully and amazingly describes the physical world around them.
III. Goals of the course

As do most (all?) other instructors of introductory calculus and physics courses, we want our students to have a strong foundation in key concepts, operations and procedures. For physics, this includes kinematics, dynamics, conservation laws, rotation, etc. For calculus this includes functions, rates of change, derivatives, anti-derivatives, etc. In addition, in order to combine calculus and physics into one coherent course, we also focus on the content goals of change and superposition, the key ideas that link calculus and physics.

In addition to these content goals, we also have a common process goal: to help our students become better problem solvers. We define good problem solvers to be those who can do the following:

- Use appropriate visual representations of the problem
- Deal with missing information or unneeded information
- Use their conceptual understanding to gain an overview of the problem and the solution
- Plan and justify an approach
- Carefully execute the plan
- Monitor their progress as they execute the plan and are willing and able to change their plan as necessary
- Check the solution in several different ways
- Learn from their solution

This can be a far cry from our students who, at their worst, hunt for an equation, plug in the numbers, and are satisfied if they get an answer even if it makes no sense.

Finally, we wanted our students to have improved attitudes about learning and about the value of calculus and physics in their own life and in their career. We also hope to help students become better learners by thinking about and monitoring their learning process.

We will go into much more detail about each of these goals in the following pages.
V. Overview of the Course

This course is the same as the standard introductory calculus and physics courses in that we cover the same topics (give or take a few), use standard textbooks, and assign grades based on homework and tests. There are several features, though, that make this course quite different:

• The order of the calculus materials is changed from the standard order (common to many textbooks) so that the students learn calculus as they need it for physics.

• Many activities are a mixture of calculus and physics. Several in-class activities combine calculus and physics concepts and operations. Differential equations are introduced because this is a key area of overlap between the two subjects. Exams are a mixture of standard physics, standard calculus, and “both” problems.

• Throughout the year students solve several open-ended problems in order to challenge and extend their problem-solving skills. Some of these are in-class problems, others are out of class group projects or individual homework problems. We explicitly discuss and model problem-solving strategies.

• Classes are two hours long (two sessions a week are calculus, two sessions a week are physics, one session is mixed).

• In these two-hour sessions, there is some lecture and much group work. During group work, instructors help students create their own understanding of the material, trying not to simply give answers, but draw out of students what they already know.

• Physics lab occurs within this two-hour session. Because the time is shorter than in standard courses, labs are not as detailed as more typical physics labs; the emphasis is on development of a conceptual understanding.

• There is a strong focus on developing students’ conceptual understanding. In the physics portion of the course, *Tutorials in Physics* by Lillian McDermott and the University of Washington Physics Education Group are a key piece in conceptual development.

• We explicitly discuss learning strategies with students.
V. Combining Calculus and Physics into one Course

The key step in combining these two courses was a reordering of the calculus topics. The usual order, given in many standard textbooks is as follows:
• Functions (polynomials, trig, logs, exponentials)
• Rates of change and derivatives (mid-semester)
• Integrals (by the end of the first semester)

Unfortunately, in the standard physics courses students learn about velocity (the derivative of position) within the first week of the course. This makes it impossible for a student to take the courses at the same time and really see the connections.

Our solution was to reorder the calculus topics to compliment the physics:
• Within the first month learn everything about polynomial functions, including rates of change, derivatives, and anti-derivatives.
• By the end of the second month learn about exponentials and logs, their derivatives and anti-derivatives.
• Learn about Riemann sums in the context of work and impulse
• Leave trigonometric functions until the end of the first semester when physics is covering rotation.

To give a rough idea of how the schedule looked, we give below a summary of what was covered in each of the eight four-week sections that made up the school year:
♦ Kinematics (position, velocity and acceleration) and Polynomials (rates of change, derivatives, anti-derivatives)
♦ Forces, more on derivatives (chain rule, product rule, etc.), log and exponential functions
♦ Conservation laws (work, energy, momentum, impulse), Riemann sums, path integrals, Fundamental theorem of calculus, optimization
♦ Rotation and trigonometric functions
♦ Oscillations, waves, imaginary numbers, solutions to differential equations with constant coefficients, integration of trigonometric functions
♦ Electrostatics, gravitation, series and convergence, integration methods (u-substitution, trig substitution, partial fractions), flux through a surface
Circuits, more integration methods, solving linear inhomogeneous differential equations with constant coefficients (applied to circuits), convergence of series

Magnetism, polar coordinates, limits

By way of explanation, the topics on series is spread throughout the second semester because we have found that this difficult subject is handled better in small pieces.

In the following pages, there is a short day-by-day description for both semesters, and an even more detailed schedule of the first four weeks.

There are areas of strong overlap between the two subjects, and some areas that are not so well connected. The subjects that are easily combined are the following:

- Derivatives and anti-derivatives connected with position, velocity, and acceleration
- Riemann sums and integrals to calculate moment of inertia and center of mass
- Work (path) and impulse integrals
- Fourier sums
- Integrals to calculate the electric field or electric potential due to a charge distribution or the magnetic field due to a wire
- Solving the differential equation for the damped mechanical oscillator, the RC circuit, and the LRC circuit
- Solving differential equations numerically for a comet falling to earth using Euler's method
- Using Newton's root-finding method to solve physics problems.

The places where we are still not of one mind

- Units - in physics can't do without them, in calculus they get in the way
- Physicists aren't careful about evaluating improper integrals
- In physics we rarely look at an entire Taylor expansion, only the first few terms.
- Physics texts often focus on constant situations (force, acceleration).
Assessment

As instructors we are used to developing curricula, but perhaps not so used to assessing the effectiveness of that curricula and then changing what we do based on that assessment.

As part of our grant from NSF on course curriculum and development, however, we needed to assess the effectiveness of our studio calculus/physics course. In this section we provide a chart of our assessment for each stated goal of the course. We used student interviews and questionnaires, and student performance on conceptual tests and standard tests.

We provide in this section two of the physics instruments (developed by others) that we used for assessment. The first is the Force Concept Inventory that measures student understanding of Newton’s three laws. The second inventory is the MPEX (Maryland Physics Expectation survey) which measures students’ beliefs about learning and about physics and mathematics.

Even when we are not developing curricula as part of a grant, as instructors we may also want to know about the effectiveness of our teaching. There are two excellent books (Classroom assessment techniques by Thomas Angelo and Patricia Cross and Classroom research by Patricia Cross and Mimi Harris Steadman, both published by Jossey-Bass) that give instructors several ways to assess what goes on in their classroom on a daily basis.

One simple way of assessing a course is to keep a daily log of what happened in the classroom each day; what was successful and what was not and what changes would probably help for next time.
First Day of Class

The following seven main items are what all students want to know the first day of class, according to Douglas Brooks, published in Educational Leadership, May 1985. The subitems are particular ideas that I have added that are only be appropriate for college students.

♦ Am I in the right room? (Write class name on the board)
♦ Where am I supposed to sit? (If you can make groups ahead of time, you need to help students find the right group)
♦ What are the rules of this teacher? (This may seem silly, but students break these rules all the time. It is easiest to make it clear the first day and then remind them later if they are breaking the rules)
   - No talking during lecture portion of class
   - You should come to all classes (unless ill)
   - If you come in late, wait to be seated
   - If you must leave early, let teacher know ahead of time.
   - Don’t interfere with the learning of other students.
♦ What will I be doing this year? What is going to happen to me?
   - Talk about the big goals of this course (increasing problem solving ability, building strong conceptual and procedural bases, developing ability to work in groups and to communicate). Note that these are valued by employers.
   - To motivate these goals, students could reflect on what kind of job they want (e.g., salary level, independence, creativity, always a new challenge). Are they ready to meet the challenges of such a job? Probably not yet. Right now they often rely on book and teacher for getting started and checking answers, use plug and chug technique without understanding, rely on knowing very similar problems to solve problems. Often have trouble figuring out how to start a problem. We want to help them to begin get out of this way of thinking. They should be able to use a strong understanding of physics and mathematical principles and problem solving skills in order to solve problems that NO ONE knows the answer to. Just as important, they must learn to check answers in several ways so that they are confident enough to risk their job on their results.
Let them know that they will have to work harder probably than they have ever had to work before. They will need to put in about 10 hours total a week for this course outside of class. Some of their friends may not have to work this hard, but they will! But we are also here to support them both inside and outside of class.

How will I be evaluated?
- Homework (You should try to hand in a perfect homework every time! It is expected that you will seek help if you need it. You should check your own answers in some way to see if they are correct. If you are not sure, check with another student or the teacher during office hours or just before or after class. Doing homework is to give you extra practice, but if you do it incorrectly, it’s no help at all!)
- Group Work
- Projects
- Tests (frequency)

Who is the teacher as a person?
- How long have you worked here?
- What other courses do you teach?
- What are your other professional interests?
- Mention any personal interests that might seem relevant.

Is the teacher going to be interested in me as a human being?
- Make it clear that you welcome them in office hours to talk about class work or other issues.
- Talk about this being a big transition from high school to show that you are aware of more parts of their life than just what goes on in the classroom!

From our own experience, it is good to talk about small things, such as
- What texts do they need to buy and where. Note if the text will be used all year or just one semester (this makes a big difference in their budget).
- What do they need to bring to class each day?
- Go quickly through the syllabus. Explain what a syllabus is (a sort of informal contract) and that they should keep it for future reference.
- What is the rhythm of the class (e.g. Fridays are combined days. Tests every four weeks. Homework due every Tuesday, etc.)
- They should spend these first few days getting organized. Buy a three ring binder to save their work in - they will need it for future reference.
Buy a stapler and a hole punch! (We can't count how many students lose papers due to lack of organization.)

- Introduce group work by doing the "how many paces to LA" problem, first singly, then in groups. Discuss why groups work. Note also that it depends on the instructors creating assignments that are appropriate (even a group can't solve any problem), and assure them that we have been developing these sheets over several years, so they are in good shape!
- Talk very briefly (10 minutes or less total) about “what is physics” “what is calculus” and why are we doing them together.
- There may be time for a pre-test, such as the Force Concept Inventory.
Grading

Grading becomes a bit more complicated for a combined class with non-standard assignments. Here are some of the details of how we did it.

- Each student gets two course grades: one for calculus one for physics. It is possible (and it has happened) that a student will fail one class and pass the other. When this happens, the student must drop out of calculus physics and repeat the portion of the class that they failed. We have also had two students who just took the physics part and not the calculus part of the class. We asked them to also attend the calculus class so that they could do the combined Friday work. Both we and the students were happy with this arrangement.
- Students are given separate calculus and physics homework that is graded as each instructor sees fit.
- **Tests:**
  - The tests have plain physics questions, plain calculus questions, and some “both” questions. The “both” questions we develop together and usually decide on the grading scheme together. But for consistency, one instructor grades the both problem for all students. The calculus problems and physics problems are, of course, graded by the appropriate instructors and TA’s.
  - Because this is really two tests (one for each class), the tests are two hours long. The logistics of grading are easier if the test packet is in two parts: one part is all the questions to be corrected by the calculus folks, one part is to be corrected by the physics folks.
- **Group work in class.** We are not as happy yet with what has happened here, mostly because we haven’t graded often enough. I think the following scheme might work well. Note that grading group work is shown to be a key part of making groups function well together (see the section on group work).
  - Give two grades, one for the product they produced and one for how well they worked together (process).
  - Grade with a check, check plus or check minus, or perhaps a five point scale.
  - Be clear about what you are looking for in process and produce. For example, groups that don’t stay on task or that don’t encourage participation of all members get a check minus. Groups that ensured
that all members understood and could explain the work get a check,
and those that were able to extend the work to other ideas get a
check plus. What you are looking for in the product would vary with
each assignment.

➢ Grade quickly after class. Note that because this is a group product,
you will not have as many things to grade as if it were individual work!
➢ Grade group work at least once a week.

♦ Attendance. We gave an attendance grade (5 out of 100 points). For
each unexcused absence up to 10 that they had during the semester, 1/2
a point was taken off of their final grade. In the end, we forgave the
first one or two absences. The point of this is to make clear that we
value attendance in class.

♦ Projects. Each project group has their own advisor who is responsible for
grading the project. Details on project grading are in the project
section. We also got together after each of us had initially assigned
project grades to make sure that all of us were grading relatively
consistently.
Room and furniture

A key to making groups work well is the room and the furniture. Here are some considerations:

- Students need to be able to face each other and work on a common piece of paper or equipment together. Some feel it is essential that students all be able to look at the common work paper right side up at all times; others feel this is not crucial. If it is important, then the group can't be larger than three students and they must be seated at a round table.
- All students in the group need to be able to point to the computer screen and use the keyboard
- Students should be able to huddle together in order to work well as a group. If they are too far apart, they won't interact well. (Among other things, this means that the chairs shouldn't be too big!)
- The instructors should be able to walk around the room easily. This means that there is adequate room between tables. You also need to think where backpacks and coats go as they take up considerable space and are inevitable.
- White boards for each group allow groups to share work with the rest of the class. Some also believe that the "erasability" encourages risk taking. There are white board capture devices that allow computers to generate hard copy of work done on white boards.
- All students need to be able to easily see the front of the room. NCSU with round tables does this with two projection screens and effectively two fronts to the room.
- Laptops are considered to be worth the extra money as they can be put away when not needed. They are extremely distracting for many students.

There are several different types of tables that encourage group work:
- Round banquet style tables, 7 feet in diameter, can accommodate three groups of three. This is used at NCSU.
- Rectangular tables allow students to face front and take notes during lecture, then turn around and work with others for group work.
• Our lollipop tables are as yet untested, but we hope that they allow students to face forward for note taking, allow for two groups of three, and also provide room for experiments.
• Groups of two students can easily be accommodated at rectangular tables.