Introduction

ABOUT THESE MATERIALS

At CU Boulder, we are just starting on a long term project to help transform the first semester of our Classical Mechanics/Math Methods course (generally taken by sophomores) to make better use of ideas and materials from the PER community.

In this folder, you will find a number of materials we have borrowed or developed. Feel free to use what you like - we would like to share materials, but also believe in giving credit to sources whenever possible.

You can download the latest version of these materials at http://www.colorado.edu/sei/departments/physics_2210.htm

If you want the course materials *including* assessments and exams, email us.
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MATERIALS INCLUDED

01 Course User's Guide
This Guide.

02 – Course Learning Goals
Detailed set of skills that students should get from this course, developed by faculty.

03 – Tutorial Guide
Instructions on how to use in-class tutorials in this course.

04 – Student Difficulties
A list of common student difficulties in several topical areas that we have observed for our students.

A – Syllabus and website
Weekly schedule, syllabus, and example dreamweaver files for a complete course website.

B – Publications on this work
Posters and papers on this transformation effort.

C – Materials by Topic
Instructional resources organized by content area (eg., Newtons's Laws, Energy). This is the recommended method of accessing these resources, as it offers a la carte access to all materials when you are ready to teach a particular topic. This section is still under development.

D – Materials by Collection
Instructional resources organized by type of resource (eg., homework, clicker questions, tutorials).

E – Assessments
Exams and Homework Solutions. You may not have this folder if you downloaded the archives from our main website – contact us for the full archive.

F – PDFs of materials
PDF versions of materials in case something gets lost in translation in other file formats. This section is still under development.

INSTRUCTIONAL RESOURCES

1- **Clicker Questions (**or “ConcepTests”). For use with peer instruction and classroom response systems
2- **Homework.** “Banks” of homework questions, with information on those problems that we assigned in these courses
3- **Lecture Notes.** Instructor notes from two iterations of the course. Each instructor has a very distinctive style, so two sets are provided so you can find the lecture notes that suit your preference.
4- **Student difficulties.** Common student difficulties that we have observed. These should be very useful documents for instructors.
5- **Tutorials.** Where applicable, a tutorial developed at CU for student-centered activities.
6- **Preflights.** Short conceptually-focused reading quizzes designed to be administered online before class.
7- **Demo lists.** These list demos used in previous iterations of the course, and other demos available at the University of Colorado. This section is still under development.

User's Guide

Included in this document:

- Text
- Course topics and ordering
- Mathematical Preparation
- Course Expectation
- Homework
- Lecture Techniques
- Whiteboards
- Recitations
- Tutorials
- Some Observations from Faculty

Text

The primary texts we used for this course are Taylor's "Classical Mechanics," (University Science Books, California, 2005) and Boas's "Mathematical Methods in the Physical sciences," 3rd Edition (John Wiley & Sons, 2006).

The following additional texts may be helpful:

1. Thornton and Marion- "*Classical Dynamics of Particles and Systems*" (This is often the text for Phys 2210, it is a similar level, perhaps a little more mathematically focused, than Taylor.)
2. Hamill, "*Intermediate Dynamics*" (Just another text very much at the level of ours).
3. Kleppner and Kolenkow, "*Introduction to Mechanics".* This is like an "honors freshman" level mechanics textbook, beautifully written.
4. Arfken and Weber "*Mathematical Methods for Physicists"* (a little bit higher level than Boas)
5. S. Lea, "*Mathematics for Physicists"*
6. Feynman, Leighton, and Sands: "*The Feynman Lectures on Physics*, *part I.*:

Course Topics and Ordering

At the University of Colorado, Classical Mechanics and Math Methods are taught together in a two-semester sequence. These materials are for the first semester of the sequence. Below is a chart developed by our faculty, which lists the content to be covered in each semester.

First Semester (2210):

Math	Physics contexts
Vectors, curvilinear coordinate systems. Quick review of vector addition, dot and cross products. Spherical and cylindrical coordinate systems, simple derivatives.	**Kinematics.** Position, velocity, and acceleration.
ODEs. Guess and check, linear ODEs, constant coefficient ODEs.	**Newton's Laws.** Reference frames, F=ma, 1D motion, 3D motion.
Line integrals. Gradient operator. Taylor expansion.	**Conservation Laws.** Kinetic and potential energy, small oscillations, momentum and angular momentum.
Complex numbers. ODEs. Fourier series. Fourier transforms(cover transforms quickly)**.**	**Simple harmonic oscillator.** Damped and driven oscillators, resonance.
Fourier series applications. PDEs. Separation of variables (in Cartesian and polar coordinates)**.**	**Heat equation. Poisson equation.**
Surface and volume integrals. Gauss' theorem. Legendre polynomials. Laplace equation. Selected Vector Calc.	**Gravitation.**
Delta functions	**Gravitation**

Second Semester (3210):

Math	Physics contexts
	Lagrangian and Hamiltonian mechanics.
Linear algebra: Eigenvalues, eignevectors, diagonalization,	**Coupled Oscillations**
	Central Forces/Orbits
	Non-inertial reference frames
	Rigid body motion
	Fluid mechanics/Continuum mechanics/ Other interesting topic?

Mathematical preparation

There are many mathematical prerequisites for this course, and students have varying degrees of comfort with this material. (See Learning Goals for detailed lists of prerequisites). Faculty may give a mathematical pre-test to students to both (a) assess where students are weak, and (b) send students the message that this is material they should already be familiar with. Students are expected to have seen complex numbers previously in Modern Physics, but are likely not proficient with manipulating them.

Course expectation

In past experience, students come into this course with unreasonable expectations for the amount of work it will require. This course may be different from what they have encountered before in terms of the level of sophistication required from their involvement in the course; the amount of time that the homework will require.

To that end, making course expectations explicit may be useful in order to prompt students to shoulder the responsibility for their own learning to a greater degree than they have in past courses. This can include giving explicit learning goals for the course (as developed by the physics faculty in conjunction with the Science Teaching Fellow), and by framing the course appropriately from the beginning.

Dr. Betterton gave a handout to her students that worked well to set the tone of the course, explaining the challenging nature of the course and the expectations in terms of student time and effort. A modified version of this is included in the "Sp-11-Syllabus" file in the "A-Syllabus-Website" folder.

<u>Homework</u>

There is a general consensus among faculty that the bulk of the learning in this course comes from doing the homework. This course is where students learn a certain level of sophistication in solving problems (*see Learning Goals*) and so assigned homework should reflect that higher expectation. The STF (Rachel Pepper) has compiled a homework "bank" of useful problems to draw on using the approaches below.

Some ideas for homework sets:

1. <u>Use the course-scale learning goals as a guide in writing HW problems.</u> This helps ensure that these goals are being met and that the HW is covering a broad range of skills.

2. <u>Assign homework other than text book problems.</u> The solutions to most text book problems are widely available on the internet. Alternatively, take text book problems and use different numbers and try not to let students know they are taken from the text (although they can still figure it out, generally).

3. <u>Assign just a few hard problems in each set.</u> This gives students time to grapple with each one in depth. This is a method preferred by some instructors.

4. <u>Assign tough "just for fun" problems</u> (for extra-credit or not). This gives the stronger students a chance to flex their physics muscles and assure that they will be challenged in the course.

5. <u>Assign the first homework problem each week as the submission of a correction of a homework problem from the previous week</u> (as done in Wieman and Perkins Modern Physics course).
    a. Identify the question number you are correcting
    b. State (copy) your original wrong answer
    c. Explain where your original reasoning was incorrect, the correct reasoning for the problem, and how it leads to the right answer.
    d. If you got all the answers correct!!! Great ... then state which was your favorite / most useful homework problem and why.

6. <u>Give two-part homework questions.</u> One part is a standard calculation problem and one part a more conceptual, understanding-based question. For example, you may ask students to:

a. *Apply the abstract formal problem to a real world problem.* Ie., use the results of their calculation to answer a question about a real life situation.
b. *Formulate the abstract formal problem when presented with a real-world problem*. This is a higher level skill that may wait until later in the semester.
c. *Formulate their expectations for what the solution to a problem might look like*, such as the direction, order of magnitude, units, sketching a field or charge distribution, or dependence upon coordinates, before beginning the problem.
d. *Explain in words what their answer means.*
e. *Explain in words what they did to solve the problem.*
f. *Justify their approach to a problem.*

7. <u>Assign homework problems with a computational component.</u> Computational skill is important for students at this level, as well as understanding that you *can* solve for the field numerically when given the code. We include some Mathematica-based homework problems in the homework bank.

8. <u>Assign some real-world ("context-rich") problems.</u> These can be Fermi problems (such as estimating the thickness on a lake) or context-rich (see, for example, http://groups.physics.umn.edu/physed/Research/CRP/on-lineArchive/ola.html)

9. <u>Assign some HW problems on a related topic from another course</u> (eg., "Gauss' Law" in E&M) to keep students focused on the big picture and emphasize that they are responsible for material from prior courses.

10. <u>Have students invent their own problems as exam review</u> We then had them pair up and do eachothers' invented problems. Students reported enjoying this. An example of how we worded the instructions for homework are included under "Review for Exams" in the homework folder.

Lecture techniques

There are a variety of lecture techniques which have been shown to be useful in student engagement.

1. Clicker questions

Many of the more simple, conceptual homework problems can be reworked into clicker questions, serving two purposes: (a) students engage in meaningful discussion about the concept rather than seeking the answer, and (b) leaving more time for longer problems on the homework set. Faculty members, in conjunction with Science Teaching Fellows, have developed a bank of clicker questions. Clicker questions have proven very effective, though time consuming, in this course, generating a good deal of student discussion and highlighting student difficulties. In addition, because students' knowledge is tested often, it is easier for them to know where their difficulties lie. One student remarked that the clicker questions in this class worked better than in other classes because they were integrated deeply into the lecture – they acted to connect one topic to the next, instead of a 5-minute aside. They were a bridge rather than a break in lecture.

Are you having trouble with the formatting in our clicker question files?

Sometimes your "slide master" may have different settings than the "master" when the slides were created, which causes formatting difficulties (like questions that are too small to read, or answers that spill off the page). See the "readme" file in the "All-concept-tests" folder in the folder "D-Materials-By-Collection".

2. Interactive lecture

When solving a problem on the board, the lecturer can pause and ask the class for the next step. If the course culture has included the use of clicker questions, so that students are habituated to actually engaging with this sort of question (instead of waiting for the smartest student to answer), then this type of discussion can occur without the use of actual clickers in every instance. The class should be given a time limit (e.g., "You have 30 seconds, write down your answer") to focus their discussion. We find that students are more likely to actually write something down on paper if the lecturer leaves the front of the room and talks briefly to students in the middle of the room.

3. Class discussions

In addition to clicker questions, faculty can pose open-ended questions (non multiple choice) for discussion in class, providing students an opportunity to engage with the concepts in class. The more that instructors are clearly open to discussion in class, the more students will feel comfortable posing spontaneous questions.

4. Tutorials

Tutorials are conceptually focused worksheet activities designed to be done in small groups during class time. They last between 10 and 50 minutes. Many of these have been adopted or adapted from the Intermediate Mechanics Tutorials available at http://perlnet.umaine.edu/imt/. The tutorials are written up separately, as is a Tutorial User's Guide.

5. Don't repeat examples from the text

Students can read the chapter as they work on the problem set. It may be useful to encourage students to read the chapter before lecture, if the professor does not intend to reiterate material from the book in lecture. In that case, lecture may be spent in productive discussion and engagement with the material. Students can easily read derivations and similar content in the book, and so professors may decide how much of that content should be included in lecture.

6. Kinesthetic activities

We have adapted a handful of kinesthetic activities from Oregon State University – for example, asking students to point in the direction of r-hat or theta-hat given that one corner of the room is origin. As a method of engaging students and maintaining their attention, it has been very valuable.

Recitations

While recitations can't be mandatory for this 3-credit course, it is useful to offer an instructor- or TA-led session to work on issues in the homework. In the reformed course, we encouraged students to work in small groups on the homework. They learn by peer instruction with occasional input from the instructor, as in the tutorials. Each group may have a group-sized whiteboard (see above), and the TA **does not** work out problems on the board, as has been traditionally the case. We have offered two homework help sessions – two nights and one night before the homework is due.