Introduction

ABOUT THESE MATERIALS

Following on the success of a similar set of "transformed" materials developed for PHYS 2210 (the first semester of Classical Mechanics and Math Methods), this package contains course materials for the second semester in the sequence, PHYS 3210.

As before, please feel free to use or modify any of the enclosed materials for your own teaching, but we ask that you give credit where appropriate. This document itself draws heavily on the original created for PHYS 2210; much of the good advice originating there still applies for the second semester.

The latest version of these materials is available on the web at:
http://www.colorado.edu/per/resources/course-materials

Comments or questions can be directed to Prof. Ethan Neil:
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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 – Course Materials
Instructional resources organized by type of resource (eg., homework, clicker questions, tutorials).

C – 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.

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. These should be considered a work in progress. They are provided in Markdown format, which can be converted to other formats (HTML, LaTeX) as needed.
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.

User's Guide

Included in this document:

- Text
- Course topics and ordering
- Mathematical Preparation
- Course Expectation
- Homework
- Lecture Techniques
- Recitations

<u>Text</u>

This follows the recommended texts for PHYS 2210.

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*.:

For 3210 specifically, the "Lectures on Classical Dynamics" by Prof. David Tong (Cambridge) are a very helpful resource for the instructor:

http://www.damtp.cam.ac.uk/user/tong/dynamics.htm

These are graduate-level notes, but can provide useful insights into some of the material, as well as a reference for students interested in specific advanced topics such as the three-body central force problem.

<u>Course Topics and Ordering</u>

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
Calculus of variations	**Lagrangian mechanics**
	Central Forces and Orbits
	Non-inertial reference frames
Linear algebra: Trace and determinant, linear operators, change of basis	**Rigid body rotation**
Eigenvalues and eigenvectors: diagonalization	**Rigid body rotation**
Eigenvalues and eigenvectors: solution of systems of ODEs	**Coupled Oscillations**
Nonlinear differential equations: equilibrium points and numerical methods	**Hamiltonian mechanics and chaos**
	Continuum mechanics (or other advanced topics, at the discretion of the instructor)

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. The use of supplemental materials targeting specific math weak points (separate lecture videos, optional problem sets, etc.) would be a useful addition and may be included in future versions of these files.

Course expectation

As noted for PHYS 2210, there can often be a large gap in student expectations and instructor expectations coming into this sequence, but by the second semester (3210) the expectations of the students are generally much better calibrated.

Homework

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.

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. *(not tried in 3210 so far…)* <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 each others' 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

Clicker questions serving three useful purposes: (a) students engage in meaningful discussion about the concept rather than seeking the answer; (b) they answer short, conceptual questions and leave more time for longer problems on the homework set; (c) they provide "checkpoints" during the lecture to refocus the students' attention and re-engage them with the material.

Clicker questions have proven very effective, though time consuming, in this course, generating a good deal of student discussion and highlighting student difficulties. Typically 2-3 clicker questions per 50-minute lecture is a good pace.

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.

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. 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. One evening a week before the homework is due is enough, although twice per week would be ideal if e.g. an LA is available to help.