Physics 3220 User's Guide

This document is intended as a "user's guide" to the materials and resources developed for this course. You should have received a zipped file with all course documents.

Included in this document:

Resources Available to You

Resources that have been gathered for this course include:

1. **This overview**
2. **Student difficulties** in this course, organized by chapter
3. **Learning goals**
4. **Chapter by chapter homework and exam problems** including real-world, approximation, conceptual, and mathematical problems, along with data and notes on student performance on selected questions
5. **Chapter by chapter banks of clicker questions,** along with instructors' comments on student performance on selected questions.
6. **Chapter-by-chapter banks of student-centered activities** for use in class and in out-of-class recitations/tutorials
7. **Tutorials** along with notes
8. **Small and large whiteboards** for use in class and group activities
9. **Library** of useful references and textbooks
10. **Conceptual post-test (QMAT)** for assessing student learning in the course.
11. **Lecture notes** from previous instructors

Text

The primary text for this course is D.J. Griffiths “Introduction to Quantum Mechanics" 2nd Edition (Prentice Hall, New Jersey, 2005).

The following additional texts are owned by the department and should be provided to you in preparation for teaching the course. If they are not, inquire with the PER faculty.

P. Tipler- "*Modern Physics*" (slightly simpler level, more 2170-like)
Eisberg and Resnick- "*Quantum Physics* " (again perhaps more 2170-like in level, although they cover lots of interesting and often advanced *examples*)
The next are all very much at Griffiths' level (and have been used or considered as primary texts in the past)
S. Gasiorowicz- *"Quantum Physics"*
R. Liboff- "*Introductory Quantum Mechanics*"
R. Robinett, "*Quantum Mechanics",*
R. Scherrer, *"Quantum Mechanics".*

<u>Other books of possible use for this course:</u>
Feynman, Leighton, and Sands: "*The Feynman Lectures on Physics*, *part III*." (Part of a truly wonderful series of 3 "introductory" physics books.)
M. Boas, "*Mathematical Methods in the Physical Sciences"* (very useful for mathematical tricks and techniques you may have forgotten)

Course Topics and Ordering

The bulk of the material in this course is fairly canonical across universities. Following are some discussions on the presentation of particular topics and where they might appear in the course.

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.

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

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

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

4. Assign tough "just for fun" problems (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. Assign the first homework problem each week as the submission of a correction of a homework problem from the previous week (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. Give two-part homework questions. 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. I.e.*, 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 sign, order of magnitude, units, sketching a wave function... 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. Assign homework problems with a computational component. 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. The amount of time spent on this topic will depend on individual faculty preference. These homework problems can

take students a great deal of time. Homework assignments using computational techniques could include:

a. Using software (such as Mathematica) to plot the wave function (e.g. time evolution of a non-stationary state in a well)
b. Writing programs to solve a solution numerically – either when it can't be solved analytically, or to compare to the analytical method.
c. Using existing code to solve a situation numerically through shooting methods, etc.

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

9. Assign some HW problems on a related topic from another course (*e.g.*, "classical magnetic moment precession") to keep students focused on the big picture and to emphasize that they are responsible for material from prior courses.

Lecture techniques

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. A bank of clicker questions has been. Clicker questions have proven very effective, if 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.

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. For example, solving for the operator method of generating the Ylm's, the instructor might ask students to evaluate various commutators needed instead of just giving or deriving them *for* the students.

3. Class discussions

In addition to clicker questions, faculty can pose open-ended questions (non multiple choice) for discussion, 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. Whiteboards

We have successfully used whiteboards in and out of class – see below.

5. Don't repeat examples from the text

Students generally 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.

Whiteboards

We use large (2x3 foot) whiteboards for group activities, and small (1x1 foot) whiteboards for individual or partner work. We have 6 large and 30 small whiteboards available for your use.

Reasons to use whiteboards:

- The instructor can quickly see what students are getting in a lecture (by walking around to individual whiteboards or by asking students to "publish" their results by holding up their whiteboards.
- Can provide more insight into student thinking and ability than clicker questions by allowing for more open-ended questioning than the limited choices presented by the multiple choice options in clicker questions.
- It gets students talking to one another
- In groups, students can work from a common discussion point and draw diagrams so that they (and the instructor) can more easily discuss together
- Because the whiteboards are, by nature, impermanent, students are less afraid to try out ideas on how to solve a problem than they are with pencil and paper

The response to whiteboards in 3220 was lukewarm (pretty neutral), so it is important to motivate and talk about why these activities are worth the time invested. The first activity using them was a "fun" experiment, to make a concept map of all of physics. It may be useful for students to see the whiteboards as a fun physics "play space."

LA Darren Tarshis notes: *"Students seem more willing to throw ideas around when using whiteboards…. Notebooks and pen and paper are far more permanent than whiteboards, so careful students may approach a problem in an overly cautious manner (and therefore thinks in an overly cautious way). Whiteboards encourage students to take more risks, try new things, without feeling that it is "permanent." This may allow students to think differently and break through intimidating content barriers."*

Prof. Steve Pollock notes in 3310: *"I've used whiteboards roughly one out of every 3 or 4 lectures this term. There are some obvious advantages, which take it even beyond the value of straight clicker questions. It gets a large fraction of the class visibly participating, it provides me with more direct feedback about their thinking (on concept tests, I only learn about student thinking as well as my best guessed distractors are!). It allows me to get students calculating (rather than just thinking about conceptual topics, a real virtue in an upper division course). I have tried using paper but students seem much more reluctant to commit a possibly wrong idea down to their lecture notebook. I appreciate being able to quickly look over their work (what's left on the boards after class.) It seems to facilitate their sharing and discussing of ideas (and I often use one board for every two students) Students seem to enjoy using them. It's similar to the role of the "napkin" at a physicists dinner gathering, (but larger, more visible and easier to erase.)*

Drawbacks of using whiteboards:

- Instructor must plan in advance to use the whiteboards (and thus bring them to class and have students pick them up as they enter class)
- The whiteboards are a little bulky and cumbersome

- Difficult for the instructor to circulate to see all whiteboards, and insufficient class time to discuss them in depth

Prof. Steve Pollock notes: *"The disadvantages of whiteboards are that I have to think up yet another class activity. It's also not always obvious what they should DO with the whiteboards. Whiteboards chew up much more time than even concept tests! The class logistics are a little awkward, esp getting the boards distributed (and then they are in the students' way if we return to a more traditional class)"*

Ways we've used whiteboards:

1 - "What is quantum mechanics" on the first day of class.
The goal here was to get them thinking about what the course was about, bringing out big ideas from 2170 (Modern Physics), as well to begin to establish a new class culture where the students would be more involved in the course. Students responded enthusiastically and had fun. It was not pedagogically valuable in this context (most students have some vague idea it's about uncertainty, or "waves", little more) but did help establish the class culture.

2 - To sketch or graph in class
For example, students were asked to sketch Harmonic Oscillator eigenstates (and psi^2) and to think about time dependence. Different people were assigned different states, n=0, 1, 2, and "large" . One group was asked to do the classical limit. (We did this activity up at the front boards, but it could just as well have been whiteboarded) In another activity, we gave them the formula for the Fourier Xform of a "square bump", and had them sketch it in the limits of very small and very small widths of the square. In both these activities, students wrestled with what we thought would be quick and simple activities, and we could watch where they were struggling.

These activities were very useful in generating student discussion, but it was difficult for instructors to visit all whiteboards and discuss with all students to ensure that the main point was understood. The activity took substantial class time, but still seemed valuable in getting students to wrestle with some key ideas.

3 - To calculate in class
Students have been asked to sketch out the beginning of a calculation, either spontaneously or as part of a clicker question. When given as part of a clicker question, the question is posed but the multiple choice answers are not displayed. The students calculate together on the whiteboards and the instructor can view their work. The instructor for Quantum 1 indicated that this use gave him a startling insight into how little students were internalizing from lecture.

4 - In group work out of class
We run tutorials (small group activities out of class) and homework help sessions. In each type of group work, large group-sized whiteboards are laid flat on each group's table. This serves as a public place for groups to discuss, graph, sketch, calculate, and gesture. Instructors in the tutorials have found them incredibly useful in this venue as the printing is large enough so that all can see, and when creating or gesturing towards certain parts of a calculation or a diagram, all can follow the discussion.

When whiteboards are (and are not) useful:

We had mixed success with use of whiteboards – this is an ongoing experiment. They seemed particularly useful when asking students to sketch something, or to do a quick calculation to answer a clicker question. Longer calculations tended to chew up a lot of classroom time for limited gain.

Another resource that may be useful to others on whiteboarding in the classroom is here: *http://physicsed.buffalostate.edu/AZTEC/BP_WB/*

Recitations

While recitations can't be mandadory 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 has a group-sized whiteboard (see above), and problems are **not** worked out on the board by the TA, as has been traditionally the case. We have offered two homework help sessions – two nights and one night before the homework is due. The effect of the recitations on student learning is being evaluated.

Tutorials

We have offered optional Friday tutorial sessions which have been largely successful. In several surveys of the class respondents who had attended the tutorials spontaneously mentioned the tutorials as being very useful for their learning. The effect of the tutorials on student learning is being evaluated. The tutorials are written up separately. In order to encourage attendance, the tutorial sessions are being offered as an optional 1 credit co-seminar starting with the Spring 2009 semester.

Our materials largely came from the University of Washington, which is developing Tutorials (and pretests) for upper division Quantum Mechanics. Those materials are still under development, and are not yet publicly available. Contact the UW PEG group for more information. We have written seven tutorials which are included in the archive.

Some observations from faculty

AH: I believe that students learn to use these fairly complicated methods only by doing hard homework problems. These should not be "cookie cutter", repeat what is done in the book kind of problems, nor "just grind through the math" problems..

TD: Homework problems should be hard and long; there should not be many problems/set so that one can think about each one for a long time.

TD: ... The more major global problem is that they often have difficulty with multi-part problems, or problems which involve a series of steps, and the steps are not spelled out crisply. I believe that this is because they are generally exposed only to problems which can be posed as short questions, which have short answers, and for which the answers can be quickly constructed, and they are not used to problems where one does not see the ending when they start.

TD: I envision these students doing technical things for a living, and all technical projects that I know of involve complicated constructions. The only way to succeed at them is to break them into parts and to solve the parts. The reason that I believe that this is a worthy goal is because this is what I see physicists doing for a living both in industry and at the university. These real-life problems are not open-ended problems (there's a deadline to submit the thesis). Thus, problems ought to have answers. (Re: learning goal: Students should organize and carry out long analyses of physical problems, involving several steps.)

TD: No real problem in physics has an exact solution. I hope students come to know that approximations are good things

AH: It is good that we start students with concepts, but at this point they have to learn to calculate. Many interesting problems in physics are complicated and we can't just think about them and come up with a solution. As professors we know what the solution is and so we make it sound natural. We shouldn't give the impression that you can sit back and think about it to come up with an answer. Can we make HW problems that are different from what we expect so that students can discover something unexpected? It is also important for them to know what to expect in a problem at the outset.

WH: My general feeling is that the average short clicker question is ill suited to address most of these goals. Perhaps they can provide some support and clarify ideas, but I worry that they are limited to short (1-2 step) problems. Maybe we can brainstorm some ways to create deeper, higher-level clicker questions rather than just having harder, more technical questions.

TM: Classes are not that flawed, but would like them to be better at math. They just need to grind through it and get practice.