CU-Boulder Physics Alumni Survey

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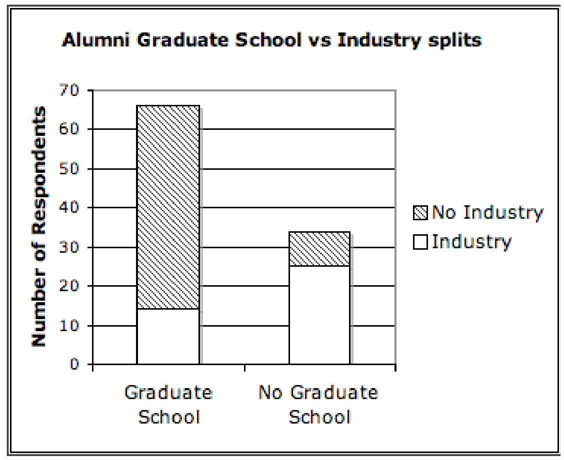
- Executive Summary -

The Survey:

- A total of 67 alumni from the physics department responded to a survey about their careers and their experience at CU. Most graduated between 2003 and 2007.
- All students graduated prior to E&M and Quantum course transformations.

Their Jobs / Graduate School:

- Just half of respondents took the GRE. They did not feel that 3310/3220 prepared them for the GRE.
- A majority (65%) had ever enrolled in a graduate program (40% currently enrolled), but a substantial fraction (35%) had never attended graduate school.
- A majority (66%) indicated that their current jobs/school were related to physics.
- Alumni not in graduate school held a wide variety of jobs, especially in industry and finance.
- More graduates included industry in their past experience or future plans (52%) than any other single job type, including a PhD program (46%).
- Those respondents who went on to non-physics related jobs, but did NOT attend graduate school were highly successful professionals with excellent grades at CU.



Two-semester courses

- Most preferred having the same instructor for two-semester courses because it provided greater continuity, but many said that it depended on the quality of the instructor.

E&M I and Quantum I

- Students appreciated homework help sessions, an instructor who genuinely cared about their learning, challenging homework, a connection between math and physics, and real-world applications.
- Students felt they *matured* in E&M I and Quantum I by learning to take control of their own learning and improving problem-solving skills. Students were less sure that they had matured as physicists in Quantum I, which was seen as a "weeder" class.
- E&MI was seen as more relevant, memorable, and understandable than Quantum I. In Quantum I, many complained about mathematical focus at the expense of understanding and the disconnection from real-world examples.
- Those who went on to graduate school found the material in these courses more relevant to their career than those who did not.

- Questions for the Undergraduate Committee -

The results of this survey are both reassuring and provocative. Overall, our alumni enjoyed the upper-division courses, and many had glowing comments (Please see the Appendix of the full report for a complete list of student write-in comments, which are interesting and informative to read). But this data also provide some important feedback on some core aspects of the major, which raise some questions for our undergraduate committee.

Are we meeting the needs of those who do not attend graduate school?

Many survey respondents, including those who were successful in CU courses, had jobs in industry and finance. However, those who did not attend graduate school felt that upper-division courses were, generally, less useful to them: they remembered, understood, and used the material in these courses less than those who went on to graduate careers, and did not feel the courses prepared them for their jobs. They were more likely to complain that these courses lacked real-world applications and lab experience. Since this represents a not-insignificant portion of our majors, how can we address their needs?

Are we focused appropriately on problem-solving and critical thinking?

Respondent reported that a main impact of upper-division courses was the acquisition of problem-solving skills, and that these skills endured after CU. The physics and math *content* of the courses was clearly less important in their future careers (see Appendix 2). Our faculty also established "intellectual maturity" and "expert problem-solving ability" as goals of E&MI and QMI. Yet, problem-solving is not an explicit stated goal of our upper-division curriculum as a whole and we do not have consensus on how to teach this ability. How do we focus our efforts in this arena?

How do we increase continuity in two-semester courses?

Alumni's primary complaint about having two instructors for two-semester courses was a lack of continuity – in terms of pedagogical structure (homework, exams, etc.) and content. The benefits of having two instructors (different perspectives on the material) could be achieved without this potential cost by increasing the communication between instructors on a two-semester course. How might we systematize course continuity?

How can we support supplemental activities from instructors?

Graduates had many glowing comments about their classes and appreciated the intellectual rigor of upper-division classes. We can learn as a department from the aspects that they appreciated about particular approaches. Extra group-oriented help sessions were seen as being particularly useful and appreciated a high level of availability from instructors. How can we support faculty in such supplemental offerings and increased contact time, perhaps through Learning Assistants or other forms of departmental support or recognition?

Can and should we increase the conceptual focus in upper-division?

In both E&MI and Quantum I, alumni complained about lack of real-world examples and conceptual focus. This was particularly pronounced in Quantum I, where many responses (see Appendix in full report) indicated that they became mathematicians in this course but did not understand the meaning behind the mathematics. Indeed, QMI appears to be a problematic course in many ways. Also, alumni clearly did not feel these courses prepared them to take the GRE. How might we address these concerns?

Table of Contents

Demographics

Survey respondents were solicited via email and postal mail from all students who had graduated with a BS from CU Physics (PHYS majors) from 1997-2007. EPEN majors were not surveyed. A total of 267 surveys were sent and 67 were completed for a 25% response rate.

Respondents were 74.2% male and 25.7% female. This is high compared to the 5-year average at CU (13% from 2003-2008), thus the survey over-represents women. For reference, 17% of physics graduates nationally are female[1].

About half (46.4%) had another major in addition to physics, generally math (48%). This is a higher proportion of double majors than the national average (37%), but mathematics is also the most common second major nationally (43%)[2].

Most had completed their degrees between 2003 and 2007 (61%), 30% had completed their degrees between 1997 and 2003.

After Graduation

GRE

About half (51.4%) took the GRE. The average GRE score reported (N=7) was 637.

Job or graduate school?

Immediately after graduation, about half applied for employment (45.3%; compare to 38% nationwide) and half applied for admission to a graduate program (52%; compare to 57% nationwide[3]). At the time of the survey, about two-thirds (66%) had enrolled in a graduate program at some point in time.

Success of applications

On average, about half (52%) of students' applications to graduate school or employment were accepted, and they submitted an average of 17 applications each (though many submitted far fewer). Most saw the success of their applications as being due to recommendations (26.5%) and research experience (25.2%). Most saw the rejection of their applications as being due to low GRE scores (30.1%) and GPA (26%).

Highest degree obtained

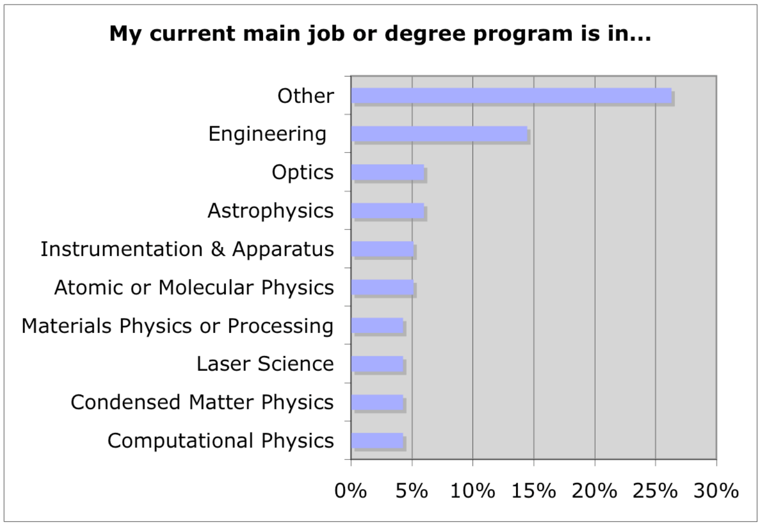
Over half obtained a BA or BS as their highest degree to date (62%), followed by MS (33%) and PhD (5%). Slightly under half (40%) were currently in MS or PhD programs.

[1] AIP Statistical Research Center, Enrollment and Degrees Report, 2006.
[2] AIP Statistical Research Center, Physics and Astronomy Senior Report, 2003.
[3] AIP Statistical Research Center, Initial Employment Report, 2004.

Employment

Area of Physics

About two-thirds (66.1%) indicated that their current job was physics related. Most jobs did not fall into a standard physics categorization (such as optics or astrophysics). The most common categorization was Engineering (14.4%), with all others being roughly equally weighted. *Statistics below are for those categories selected by at least 4% of respondents.*

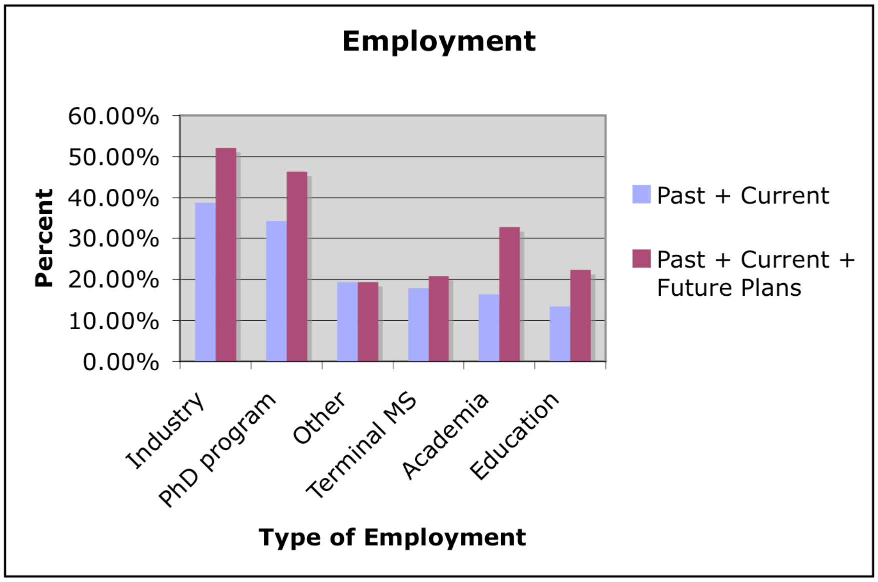


What are their jobs?

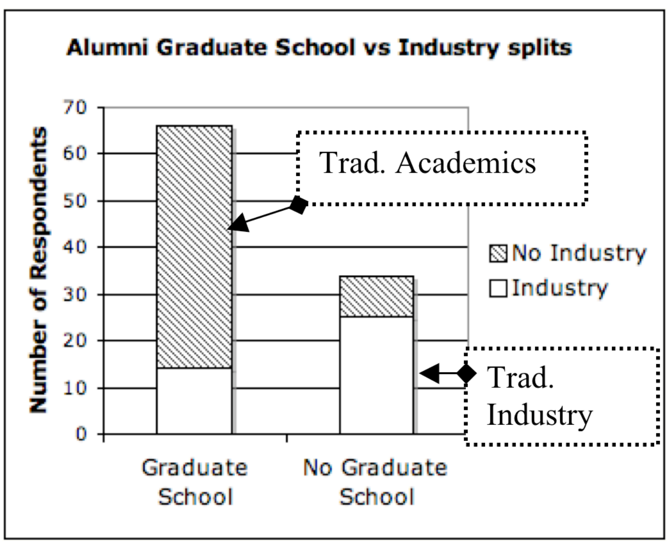
Some of the jobs listed, other than graduate programs, were:

- Strategic consulting
- Staff engineer
- Financial advisor
- Financial analyst
- Actuary
- Stress analyst
- Laboratory manager
- Data analyst
- Science Discovery
- VP of finance
- Satellite integration engineer
- Aerospace system engineer
- Technical writer
- Religious studies
- Sales engineer
- Foreign service officer
- Paramedic
- Research analyst
- Patent examiner
- Pastor
- Associate scientist
- Manufacturing lead
- Solar electric installation
- Project manager
- NASA educator
- Production coordinator
- Naturopathic medicine

Career Path
Industry and PhD programs were the most common categories for past, current, and future employment combined. For percentages, see below.

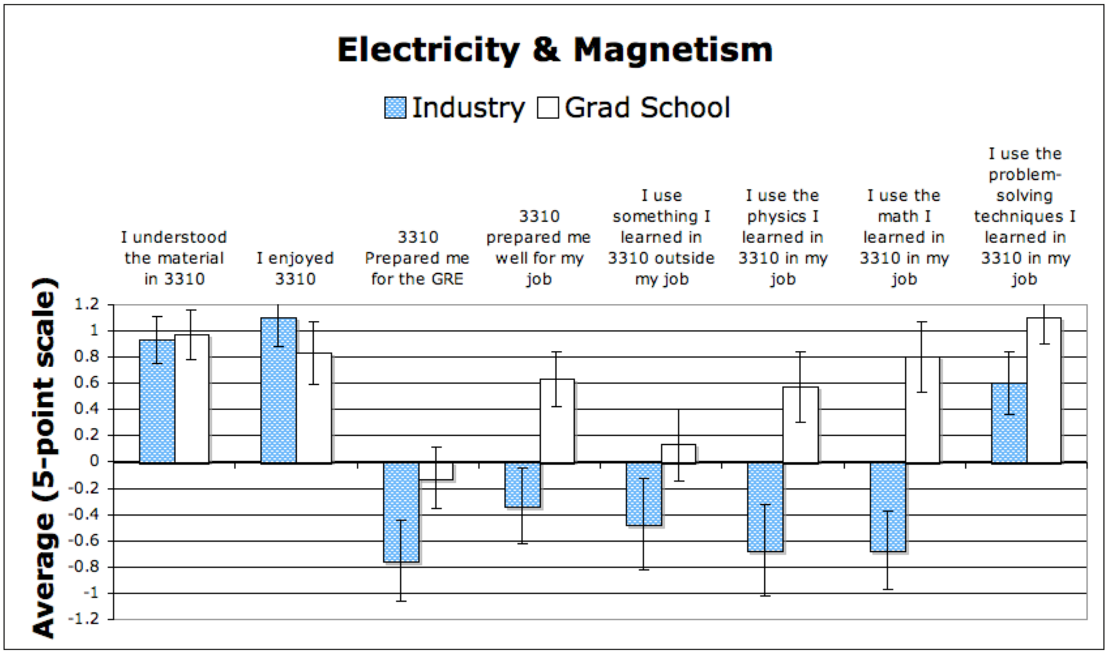


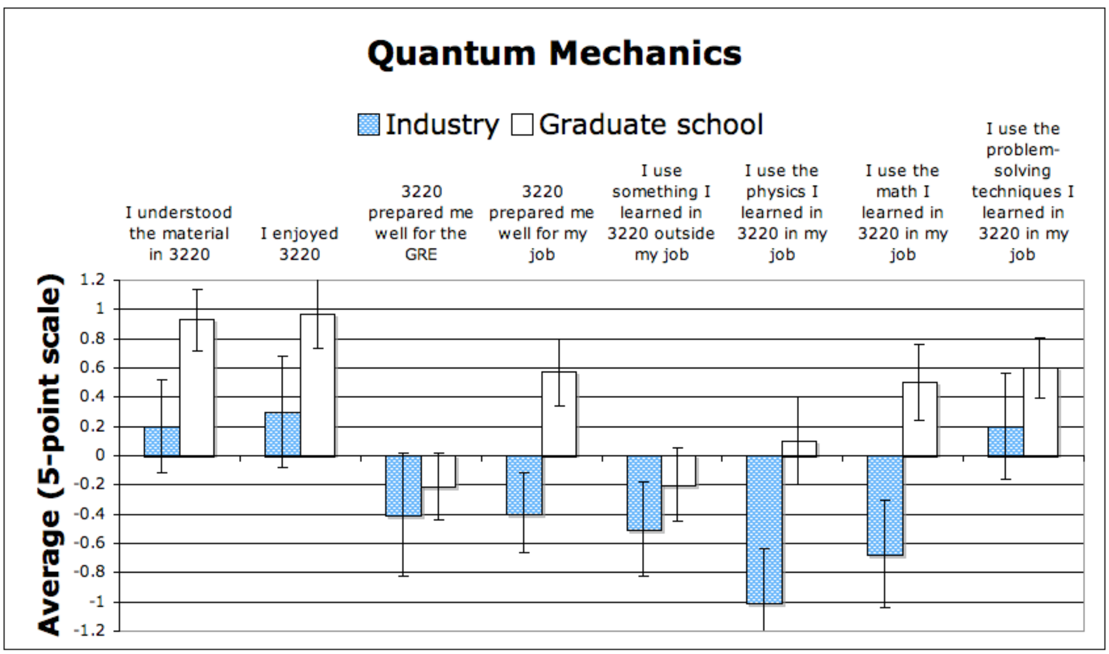
If we examine the overlap between alumni who enter graduate school and those who have jobs in industry (considering only past and current employment or enrollment), a pattern emerges such that most students who go on to graduate school are *not* employed in industry and those who are employed in industry do *not* go on to graduate school. These are the typical groups of interest – students bound for academic pursuits versus those who have a career outside of academia. We'll term these "traditional academics" and "traditional industry" to differentiate between the two career paths.



Effects of Career Path

Who are these two main groups of alumni, and are we serving each of their needs? For one, traditional academics had better grade points in 3310 and 3220 than did the traditional industry-bound graduates: 3.6 vs 3.0. The traditional industry-bound graduates also seem to be less well-served by 3310 and 3220, as illustrated by their responses on an attitude survey. The questions were answered on a 5-point agree/disagree scale –a positive score indicates agreement and a negative score indicates disagreement. Those who went on to graduate school answered with respect to their graduate research.

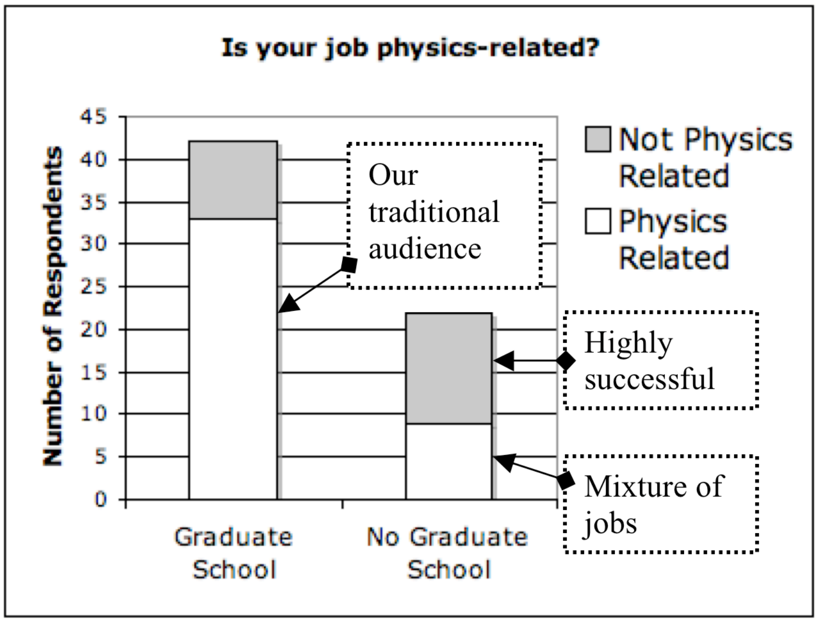




The traditional academics were more positive about both courses in many aspects, including remembering, understanding, and using the material in the courses, enjoying and understanding the course, and feeling that the course prepared them for their job or graduate school, though only some of these results were significant[4]. Overall, Quantum Mechanics (3320) was seen less positively than E&M (3310), though most differences were not significant. This raises the question of how we might make these courses more relevant to those going into industrial jobs.

Physics and Non-Physics Related Jobs

Not all respondents were employed in physics-related jobs or in graduate school related to physics. Below are the percent of respondents who are in physics-related jobs, broken down by whether they went to graduate school. Not surprisingly, those who go on to non-physics jobs felt less prepared for their jobs by these upper division courses than did those who went on to physics related jobs.



Most alumni who enrolled in graduate school are in physics-related jobs or graduate programs. Those who are not in physics related jobs are still in high functioning positions (VP of Finance, dental school, financial engineering, staff engineer, actuary, software engineer, etc.)

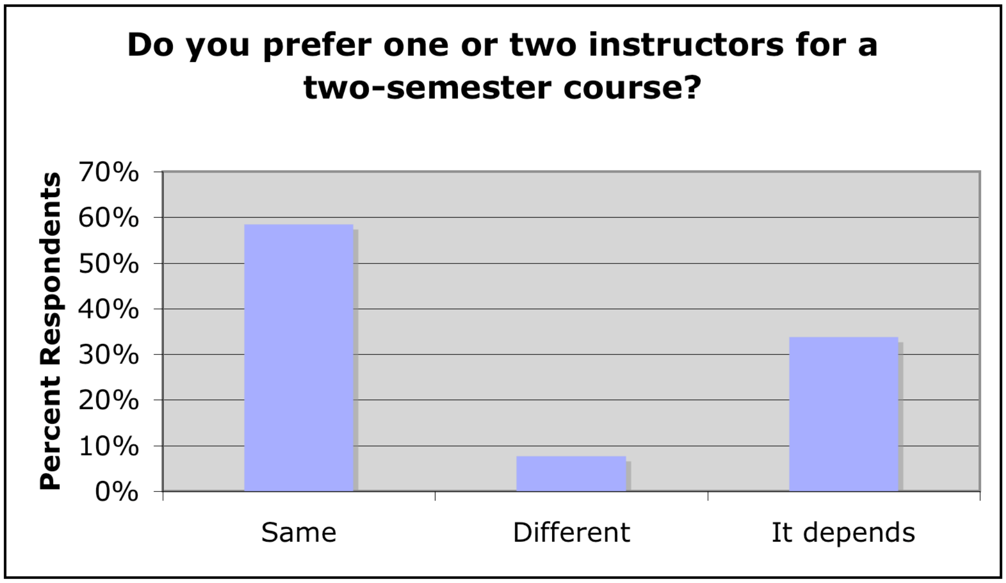
But what about those who did NOT go on to graduate school? We find some interesting differences when we examine this group. Those who went on to physics related jobs without a graduate degree have a variety of positions (electronics, lab and safety manager, scientist, aerospace engineer, optical engineer, manufacturing lead, sales engineer, data analyst). However, when examining those with NON physics related jobs we find a group with highly functioning and highly satisfying jobs, across the board: Foreign service officer, financial advisor, product manager for PayPal, systems engineer at Microsoft Virtual Earth, computer

[4] Specifically "3310/3220 prepared me for my job," "I use the math I learned in 3310/3220 in my job," and "I use the physics I learned in 3310/3220 in my job."

engineer, financial analyst, paramedic, and research analyst. These alumni got similarly high grades in upper division courses as did those who went on to graduate degrees. Thus, our graduates can be highly successful professionals even if they leave physics and do not receive a graduate degree. How can we ensure that these students' needs are met?

Two-semester Courses

Respondents were asked to reflect back upon their experiences at CU and indicate whether they preferred the same instructor for both semesters of a two-semester course, or different instructors.



Arguments in favor of having the same instructor:

- Continuity and cohesiveness in course content (instructor knows what has been covered)
- Continuity in course approach such as grading, pedagogy, exams, and homework

Arguments in favor of having different instructors:

- Allowed students to experience a diversity of teaching approaches
- Allowed students to experience a diversity of frameworks/perspectives on the physics
- Allowed students to "escape" from an instructor who was not seen as "good"
- Allowed students to "escape" from an instructor that they personally did not enjoy

Most of the difficulties associated with having two instructors could be addressed by greater communication between the instructors teaching the first and second semesters of a course – an idea that has been mentioned within the department before.

For student write-in responses on this question, please see <u>Appendix 3.</u>

Classroom Practices

Respondents provided many comments on things they appreciated about particular instruction methods in E&M I and Quantum I. Common traits that students appreciated were:

- Out-of-class homework help sessions, especially ones where they were forced to work or explain the problem themselves (rather than watching someone else do it)
- Cooperative group learning (both in-class and in help sessions)
- Respect from the instructor
- An instructor who gave a lot of their time to the students and genuinely cared whether they learned the material
- High expectations from the instructor (including difficult and interesting homework), as long as they felt the instructor genuinely cared about their learning and was available.

Sample Respondent comments

Additional comments in Appendix 5. They are a valuable read.

Some students want personal attention from instructors:

> *He forced you to learn a lot but took a lot of time out of his day to help students.*

> *Prof. XXX's personal attention and enthusiasm for the material were also invaluable.*

> *I liked homework help sessions that encouraged students to solve problems on the board and in front of the class. A cooperative working environment*

> *He was always available for his students and never gave you the answer, but would take the time to help you figure out the answer yourself*

Some want more connection with the concepts:

> *I learned very little physics – only math. It was often not clear how the math and physics were related.*

> *Prof XXX always provided nice intuitive examples and explanations to make crazy math have a nice meaning*

Some really like how tough this course is:

> *Prof. XXX expected a lot from us. The teaching style of XXX and his expectations drove us to do better.*

> *The course probably could have moved a little quicker especially since the material in E&MII was more difficult, I thought.*

> *Homework was too easy and in-class examples were too sparse.*
>
> *(I liked) long interesting homeworks and long office hour sessions sweating out problems on the board.*

Physics 3310: E&M I

Intellectual maturity

Most respondents (85%) felt that they had matured as students and physicists during E&M I. In particular, they felt they learned to:

- Improve their problem-solving skills and to persevere to solve long difficult problems
- Be more confident in their ability to attempt difficult problems and overcome challenges
- How to work hard, study better, and enjoy learning for its own sake
- Improved their math skills

How do they use material from the course?

For the most part, respondents say they understood, remember, and enjoyed the material in E&M I to a moderate degree. Those who went on to graduate school (58%) remember and understood the material better and feel that the course prepared them for their career, and use the material *outside* of their primary job more than those who did not go to graduate school (31%). Both groups use the problem-solving techniques equally. *For full results from this portion of the survey, see Appendix 2 (page 14).*

Suggestions for the course

Based on student comments, suggestions for this course are:

- Keep giving challenging problems in lecture and homework
- Provide homework help or study sessions where students work through problems
- Provide more connections between the material and real-world applications, such as a laboratory experience, use of demonstrations, and job/industry applications
- Improved connection between math and physical concepts.

Notably, those students who had never enrolled in a graduate program accounted for the vast majority of those asking for more labs and real world/industry applications.

> *More real world examples. They never showed us how these things we were learning related to the real world*

> *(I liked) challenging problems, with lectures that gave you enough information to get started and work through them*

Physics 3220: Quantum I

Intellectual maturity

Fewer respondents felt that they had matured as students and physicists during Quantum I (71%) than E&M I (85%), and many responses showed uncertainty about this question. Several (N=7) mentioned that this course made them reconsider their major and it's a weeder course, though there was only one such comment with respect to E&M I. In particular, they felt they learned to:

- Improve their problem-solving skills
- Buckle down and work really hard, read the book, and take responsibility for asking questions when they didn't understand something.
- Think about why something was true (e.g., by understanding the theory) and wrestle with abstract concepts
- Use mathematics to understand the world (and that it could be more powerful than intuition)

How do they use material from the course?

Across many different questions, graduates felt they understood, remembered, and used the material in Quantum I *less* than they did the material in E&M I. Paradoxically, those who went to graduate school reported enjoying Quantum I *less* and felt that Quantum I prepared them *less* for the GRE than did those who did not go on to graduate school. *For full results from this portion of the survey, see Appendix 2 (page 14).*

Suggestions for the course

Overall, students really seemed to enjoy the content of this course, but had very mixed reactions aside from that. Unlike E&M, there were fewer glowing comments, suggesting that we haven't yet "nailed" how to teach this course. Many complained about the mathematical focus, at the expense of understanding. Based on student comments, suggestions for this course are:

- Have a better connection between Quantum I and Quantum II
- Make a better connection between the math and the physics
- More conceptual focus
- More emphasis on where Quantum applies in the real-world

> *I spent so much time getting a grasp of the math that I do not think I learn very much about Quantum Mechanics at all.*

> *(I would have liked) more connection to reality. Sophomore lab was all about QM and modern physics; why don't profs seem to know this and allude to them as examples during lectures?... More analogies would have been helpful… Conceptual understanding is what I really missed with these two course sequences.*

Conclusions

In summary, we surveyed 67 alumni from the CU Physics program. Students follow a variety of career paths, with about half enrolling in a graduate program immediately upon graduation, and an additional 16% enrolling by the time of the survey. Our graduates are, overall, quite successful by most standards, with career paths in academia and a variety of high- and low-profile positions in the private sector. About 1/3 have career paths outside of physics. Those alumni who did not seek graduate degrees, and are not employed within physics, are highly successful professionals.

Students greatly appreciated the intellectual rigor of these courses, but many wanted more conceptual and real-world connections (especially in quantum mechanics). Personal attention and time from instructors was a plus. There are some ways in which these courses do not appear to be meeting the needs of some students; particularly those who do not follow the academic career path. Those students specifically asked for more real-world examples and labs, and indicated that these upper division courses did not prepare them well for their jobs and they do not use the material from these courses in their jobs.

Students are concerned by the lack of continuity in pedagogical technique and course content between the first and second semesters of two-semester courses. Since it is useful to expose students to a diversity of teaching practices and perspectives on physics, greater communication between instructors on these courses seems prudent.

These results are not definitive by any means. This is a limited sample with some bias in response. However, these data show certain avenues of employment that we were not currently aware of as a department, and allow us informed insight into how the upper division courses serve our graduates after they leave CU. These results raise some worthwhile questions for the undergraduate committee as we consider the purpose of these courses.

APPENDICES

Appendix 1: Write-in Responses on Two-Semester courses

Below are student responses to the question "Do you prefer one or two instructors for two-semester courses?"

In favor of different instructors:

- As long as each professor is aware of what is taught by the other, the diversity of approaches outweighs the lack of continuity.
- Multiple instructors yields different approaches to problems, and different ways of explaining physics. Some professors stress concepts and some professors stress longer problems. A good student needs both.
- It is nice to have continuity - by having the same professor both semesters, students know what to expect, and don't have to readjust to new methods of teaching/testing. However, I appreciated having multiple perspectives on the topic by having different professors teach the courses. Additionally, if a student doesn't learn the material well from one professor, they might be able to learn it better from another. It's almost a toss up between the two, but I lean more towards a different instructor for each semester.
- Having different instructors for the two semesters was helpful (for QM) in that we received a broader perspective than the classes with the same instructor (E&M).

In favor of the same instructor:

- For E&M Prof X was the instructor first semester and Prof Y taught second semester; Prof Y was a harder teacher but I learned MUCH more. In this case I was glad we switched, but it would have been better if Prof Y was the instructor from the beginning.
- I had Prof X and then Prof Y for E&M I,II. They had different ideas about how to teach the course, and we lost about of month of E&M II to Prof Y trying to make us match his expectations/style before we could really get to learning.
- For QM Prof A was the instructor first semester and Prof B was the instructor second semester. In this case Prof A did a good job teaching us but it wasn't up to Prof B's extremely high standards; consequently I felt very under-prepared to take QM from Prof B and would have preferred to stick with Prof A.
- If the professor is good then both semesters should be the same professor.
- It really depends on teaching style. But, normally keeping the same instructor is good because they know exactly where to pick up after the first semester.
- I had different professors for both semesters bit looking back on my experience I would've preferred having the same teacher both semesters. With that said, the teachers for e&m and QM should be the absolute best teachers in the department.
- I found the personal rapport I developed with my E&M instructor over both semesters made it easier to ask questions and seek guidance, where the same was not true concerning quantum Mech., for which I had two instructors.
- E&M I and II I think should be taught by the same professor to provide continuity. This class (taught by Prof Q) as an undergraduate was what best prepared me for graduate courses.

- I had one instructor for that class and I believe the coherency between the two classes afforded by using the same instructor was helpful in clarifying the concepts.
- I prefer continuity of instruction.
- Usually good to have a cohesive experience and framework. Especially when using the same textbook. Class format, hw/exam format, instructor teaching style, all of those are know and don't have to be figure out for the second semester. I see that as a good thing.
- When I had two different instructors I felt like we either repeated information or the instructor assumed we had knowledge that we didn't instead of building on existing knowledge
- E&M is essentially one long course, broken into two semesters by necessity. A single professor provides better continuity in how the material is presented, and makes E&M II that much more efficient.
- Having the same instructor would help since that instructor will be well informed of what materials he taught.
- There is too much difference between profs in terms of book choice, grade breakdown, grading, teaching style, course goals, assessments, etc.
- The instructor was able to relate better to previous information since he/she taught it to us.

It depends…

- I don't think the approach (same vs. different instructor) mattered as much as the quality of the instructors -- in my experience.
- If you had a good experience with your professor in your first semester, than it made sense to have them for next semester. However if you didn't prefer that professor, you get a chance to try the approach of a different professor.
- Depends on the quality of the professor; Prof Q was excellent.
- It really depends on the teacher. If the teacher is dynamic and good with the students, then they should continue with them. But if a teacher isn't very good, then it would help to change it up a bit.
- Depends on the instructor
- Hard question if your teacher for the first semester was good of course you want to have that same experience repeated. On the other hand if the teacher was no so good you want or need someone different. Most teacher in the physics department very good physicist especially in their given field however this does not always translate into the classroom. For example I took E&M 1 and 2 from Prof C which was an excellent experience.
- It depends on the teacher. Feedback from the students from the class in question should dictate the approach.
- If the instructor was a good one I'd rather have the same for both semesters. If the instructor is bad or I didn't like them, I'd rather have a new one second semester.
- This gives a sense of continuity and allows for development of more classmate & teacher lines of communication. However, if you don't like the teacher you're stuck for a year. Still, there are enough good teachers at CU that this is a good thing.
- If the instructor is good it is great to have the consistency. Otherwise, it is better to have a chance for someone else to teach
- Same instructor can get monotonous, however it is not necessary to learn a new teaching/learning style
- The single professor approach applies the success or failure of a given professor. As such single professors teaching multiple semesters must be exception. 'Ordinary' or 'above

average' is not sufficient to justify the risks involved therein. Teachers in the first approach must not assume that the students were present for the first semester. My first semester at CU I was penalized severely because I started in the second semester of one of these two semester classes. The teacher assumed that I understood a notation that was taught in the previous semester.

Appendix 2A: Write-in Responses: "Did you mature as a physicist or a student in E&MI (3310)?"

- I definitely matured since the problem sets were much more advanced then anything else I had worked on prior to that point.
- Not in this course, but that semester was the hardest semester I ever had, and I definitely matured as a physicist because of it.
- E&M, more than any other undergrad physics class, teaches you to sit down with a physics problem that can take pages to solve and not wince. After that, you're not really intimidated by big hairy problems.
- Yes, by expanding my mathematical tool kit.
- Both. I had to learn not to use those mathematical techniques for solving real physical problems. As a student, it was around this time that the major became more intensive and studying well, and long, became important.
- Yes, as a physicist and a student. I became more confident in attempting problems, and more interested in trying complicated problems that would teach me new physics. I also became better at teaching others how to think about and solve these problems.
- Yes. I learned how to communicate, study, and solve physics problems. I learned how to overcome challenges.
- No. Prof X was trying way too hard to be a cool teacher, focusing on concepts and not computations. Homework was too easy and in class examples were too sparse
- Yes. I thought Prof Z's genuine interest in the success of his students was the most helpful part. While I don't consciously apply physics to my everyday life, I apply the same approach to learning that I learned in this class.
- As a student, I learned the value of trying the think of the problem vs plugging in a simple equation.
- Definitely. This was much more involved then previous courses. I learned more vector calculus in E&M, t hen in any math course I took.
- Yes, improved my math skills
- No. I had not yet made the mental transition necessary for stepping between lower and upper division classes. I really wish I had taken it more seriously.
- Yes... I was humbled by how difficult the course was for me.
- I matured as a physicist. This course took me to a level of physics that only Quantum Mechanics was able too.
- As a student, I learned to put a lot more effort in my work.
- I must have but I can't remember anything anymore.
- Yes I did. It was the first semester that the physics students really started getting into the nitty gritty and learning what studying physics is really like
- Yes. My handwriting improved dramatically, since he would not accept sloppy homework. More importantly I began to enjoy physics itself not just the fact that I received good grades. There was a transition between learning to receive grades and learning for the sake of learning.
- Yes, I was a sophomore taking the course and pushed myself to a level I was challenged and found some limits. Again, the depth of those limits were largely set by having such a strong prof.
- yes, learned better ways to study (wish I'd learned this earlier!!)
- Yes. Dr. R gave me a fundamental understanding as to how these theories came about, not just how to use the theories.
- I would say yes. The level of understanding pushed me to my boundaries and made me a better physicist.

- Yes, a lot is assumed of students when we walk into 3310, for example it is assumed we know all about D.E. and Calculus I,II,&III so having to pull all of these things together again puts them in a less abstract light, and starts to make them as part of ones natural language, in order to try and describe things.
- I don't really recall anything, so I would say no.
- Yes, although I would say the maturation process began in my classical mechanics course.
- To be honest, I think I matured as a student more in mechanics
- I believe that I did. It is the first course that goes into more advanced physics. Physics 1 and 2 are great survey course. And Modern is also a good survey course. It was not until E+M 1 that I began feel like I was thinking and acting as a physicist. I was able to determine the problems and concepts associated with the field and than became able to start to answer those problems.
- Yes, continued to develop math skills, study skills, problem solving skills, and abstract thought
- Yes. I remember this was the first class where we really began gathering as groups to work through the homework. I learned how powerful discussion can be for learning.
- As a student, definitely - hitting junior-level E&M is like making the big leagues in baseball, since the small and easy stuff is pretty much over at that point.
- Definitely. As I said above I think this was the first time I really took to heart learning the rigorous mathematical proofs behind electrostatic problems. This was mainly due to Prof Q. going step by step through the proofs. It is my model for my research now, and having a solid foundation of the proof helps immensely when defending answers to much more complicated questions
- Yes, like I said in 5 I feel like I improved my problem solving techniques.
- "Absolutely not. Expectations in this class routinely exceeded reasonable expectations. The class average for the 1st exam was below 20%
- The class was good preparation for graduate school. After this class I found that graduate level EM was remedial in comparison.
- The class was a waste of time in so much as it prepared me for physics employment."
- Professor L really helped me grasp Electricity and Magnetism concepts from the ground up, and many valuable lessons in terms of your attitude towards studying a subject.
- Yes, Prof S helped us to think.
- Yes, make it a challenge.
- Maybe. I hated this course and nearly changed majors because of it. But I stuck with it and moved on.
- I don't think this class affected my maturity.
- Yes, this was where the real work started. I think it makes or breaks someone & tests whether they really want to major in physics :)
- Yes, it was one of the first in depth courses, not just a guide [?] overview
- Yes. I learned a great deal about differential equations, vector calculus boundary value problems, classical field theory, relativity, unification[?] of phenomena and the history of physics.
- Yes. I remember my junior year as the year college became very serious. I became a better student through studying E&M with my classmates late into the night in the Physics basement.
- Yes, I was better able to follow long proofs and think and solve 3 dimensionally
- Yes. Properties of energy, magnetic properties,& currents were explained with thorough explanation, thus learning was simplified.
-

Appendix 2B: Write-in Responses: "Did you mature as a physicist or a student in Quantum I (3220)?"

- Yes. Prof R was a phenomenal teacher and I learned how to approach problem solving in a very rigorous manner.
- I suppose, just through learning the basics of QM.
- probably, I think I withdrew from this class the first time I took it. This time I at least passed.
- I would say yes, though at the time I did not know it. The work was mostly done on my own as the lectures did not seem to clarify things much.
- Yes. There was no fooling around in this class. Up to this class everything had been crazy easy. I had to change my approaches to thinking and learning to something more like how I do now.
- I felt pretty lost through this class though my grade doesn't reflect that
- Yes, I learned that I probably wasn't fit for physics as a career.
- A physicist and being able to mature as a scientist being able to create ideas / hypothesis about how and why something is occurring
- yes. I became aware of the extent I didn't know about physics.
- Not really. It was more a course in mathematics, but intro quantum should be.
- Prof B is another of the great prof's I had, and he was more of a nurturing prof that got me to take initiative on my own to study the topic.
- i guess - it changed my career path
- Perhaps. I feel in this class that I lacked a more fundamental understanding of the theory.
- Yes, In this class I had to learn to trust the math more than my intuition.
- No. I didn't really do this until I got to grad school and really had to start using the things that I learned. Although, it has become clear that I learned more than I thought I had.
- Yes, in that I learned how to use math to shape my intuition.
- The course was both exceptionally challenging and rewarding. Prof. D's style and methodology more closely hue to graduate courses than undergraduate, making the experience quite useful.
- Yes, learned how to put in long hours making little-to-no progress, before eventually finding the solution.
- No, I matured as a mathematician not as a physicist.
- Absolutely, really had to grow to wrap mind around abstract concepts presented. Really just had to work through it... one confusion problem at a time.
- Yes, taking more responsibility for my learning
- The first semester of quantum mechanics is always a turning point for physics students... before 3220 most of the material dealt with is classical physics (even E&M). Quantum 1 is a jump into the cold pool of higher level physics.
- As a student - learned that sometimes the breaks don't go your way. As a physicist, I managed to pick up a working vocabulary of QM, but I wouldn't have felt comfortable moving into a graduate program in physics with what little we learned from the course.
- Yes, it's really hard to not mature as a physicist in your first exploration of quantum mechanics. To me, it's what really separates the physicists and engineers in undergrad.
- It was nice to learn that we could describe the 'quantum weirdness' using mathematics
- Yes. QM exposed me to different aspects of physics.
- Reinforced me to pay very careful attention in class.
- After the ass kicking I had taken in Phys 3310, Phys 3220 gave me my confidence back.
- Yes, again tests one dedication to the major. Also, this class we used Mathematica a lot which started my programming career.

- Yes, I learned to ask questions when I didn't understand what is going on.
- Yes. I began to understand the principles of an entire realm of nature.
- Yes, in that half my late night homework time was spent on QM.
- Yes, I understood better the complicated math, though I forget it all now.
- Yes. This is where I started to read the book before class [duh-everyone should do this but few do] and gained confidence that if I didn't understand something I should ask.
- Yes. Physics of atoms was another area of Physics which involved principles of similarities yet distinct differences.
- Yes, through struggle.
- Nearly dropped out physics due to this class.

Appendix 3A: Write-in Responses about E&MI (3310) – Suggestions for Improvement or Aspects Liked

- The homework problems in the book were different enough from the examples in the text that you really had to apply the ideas of the chapter. This is in contrast to a lot of my math classes where the homework problems were the same as the examples.
- Textbook
- The pace of the course should have been faster, there was too much time spent on each individual concept.
- Clickers!
- A longer time would have provided a more in depth study of the various subjects, rather than glossing over each of them
- Challenging problems, with lectures that gave you enough information to get started and work through them.
- Homework help sessions that encouraged students to solve problems on the board in front of the class. A cooperative working environment. I liked that we were taught slightly above the Griffiths E&M text,
- more 'real world' applications of E & M
- maybe a more fundamental approach to help ease the learning curve.
- I learned very little physics - only math. It was often not clear how the math and physics were related.
- Making labs available that go along with the course that follow the topics and show students how and why, not just how something works.
- More real world examples. They never showed us how these things we were learning related to the real world. through my own reading after i graduated that i found out that the stuff I was learning actually was used.
- Solving lots of problems on the board is good.
- I would like more example problems, worked all the way through, in class.
- The use of index notion for vectors was very useful, especially when doing vector calculus.
- I liked the study sessions that Dr. Q would hold once or twice a week.
- I liked learning how to use physical symmetries to help solve problems.
- Dr. L ran homework help sessions. This improved my performance on the exams substantially.
- Dr. R had good homework review sessions
- An intensive lab.
- I liked how Professor L had us work on problems in groups during class and then have students go to the board to solve the problems.
- Emphasis on the skill sets as opposed to emphasis on solving the same set of problems.
- Provide explanation of methods, not repetition of steps.
- Professor Y hosted STUDY sessions where we would each have to go to the board & work through the problem set in front of the whole class. It definitely made you learn
- More labs aligned to the theoretical work; make it required to do it together.
- Homework study sessions led by Horanyi were helpful
- CU has an excellent stock of demos. I'd like to see profs for jr & sr courses take advantage of that resource
- Connections from E&M 1&2 to senior level courses would have helped.
- A connection to real jobs & industry helps the student for its uses.

Appendix 3B: Write-in Responses about Quantum I (3220) – Suggestions for Improvement or Aspects Liked

- Taking QMII with Prof X made me wish we were more rigorous with our mathematics in QMI.
- I liked The philosophy behind it
- The math notation is very complicates.
- I did enjoy learning about complex variables and fourier analysis.
- I liked Lots of homework problems instead of exams. Meant that we spent a lot of time actually learning instead of reviewing.
- I would have liked A better foundation on the necessary math skills.
- Prof T always provided nice intuitive examples and explanations to make crazy math have a nice meaning.
- I would have liked More operator mechanics (with bra-ket notation) and less wave mechanics. I think operator mechanics gets at the core physics more easily.
- I love learning about quantum physics and the principles of reference frame vs. moving frame.
- A lab with more specific lessons would be useful
- It could have prepared me for quantum 2 more.
- The study hours outside the classroom Prof B had. Tons of students would show up and I learned more with that setting combined with the classroom
- It was a rude and uncomfortable transition from classical mechanics to quantum mechanics. I feel that the instructor should help students bridge the fundamental differences between what he/she was taught before, and in this class.
- I liked the format of the class, starting off with simple square wells then increasing in difficulty.
- I would like more guidance from the instructor as to how and when Quantum mechanics applies.
- I liked the way Prof G did a very good job in articulating things in such a way that they were easy to at least accept. Also Prof G did do a few demonstrations, for example he did the double slit experiment with a laser, and seeing it helped it be a lot less
- the PHeT program is great. I have played around with the Java applets, and I see them as being very helpful.
- I really liked the abstract nature of it, but I'm not sure this helped me learn it any better.
- I left that class without a good understanding of completeness, which would have been useful in the second quarter of the class.
- I liked Challenging, sometimes outrageous, homework sets
- I spent so much time getting a grasp of the math that I do not think I learn very much about Quantum Mechanics at all. The course either needs another semester or be aimed more towards conceptual learning. After the completion of the two semesters I felt I had a good grasp of the math used in quantum mechanics but not of QM its self.
- Many students had a hard time grasping concepts because they were so abstract... A strong linear algebra background makes this course go much smoother.
- A broader explanation on the concepts behind the math.
- I think the class could start even more slowly with the basic concepts. I remember having to struggle for a while because the class had progressed too fast to 'more interesting' topics instead of really hammering at the basic concept of a Hamiltonian, eigenfunctions, eigenvalues, etc
- The interesting new physics made it easy to pay attention and motivated my to study the material further than in the class.

- I liked his questions on homework and exams. They weren't very hard, but they always combined two concepts in very achievable fashion
- At the time, I was in want of more history and more in depth study of the basic principles. I thought we might have learned too much. However, having gone through grad school I think I understand much better that an introduction to many topics is better than a deep study of a few.
- I would have liked More emphasis on theory and broad concepts. A minor reduction on math tools.
- I would have liked: Maybe learning the Bra-ket notation early. I knew linear algebra, but a firm basis in Bra-ket notation would have sped things up. Also, path integrals were mentioned, but not really covered.
- I would have preferred: Don't use Mathematica!! I wouldn't add content- it'd get too cluttered
- I would have liked: Slow down
- I would have liked: Again, more connection to reality. Sophomore lab was all about QM & modern physics; why don't profs seem to know this and allude to them as examples during lectures? Also, with concepts as removed from everyday experiences as QM, more analogies would have been helpful. Or you could just have Gamow's book 'Mr. Tompkins' be required reading; it's a great way to get the concepts. Conceptual understanding is what I really missed with these two course sequences.
- I would have liked: Perhaps it's uses in today's age of environmental areas.

  Suggestions for future: Speak English - Not math. Give examples - This is strange stuff. Don't say the same the the same way again & again. There was a lack of conclusion or goal to this class. Luckily there were several more quantum classes to take.

Appendix 4: Survey

Note: Most surveys were administered online

CU Boulder Physics Graduate Survey

About you...

I received my BS in Physics in ______ (year)

I am ☐ Male ☐ Female

I had another major in addition to physics
☐ Yes ☐ No
If Yes, what was it? ____________

I took the Physics GRE
☐ Yes ☐ No
(OPTIONAL) GRE Score: _______

Within a year of graduation from CU, I applied for
☐ Employment
☐ Admission to a graduate program
☐ Other ______________

How many of your applications were accepted? _____
Out of how many? _____

What do you think were the key factors in the *success* of your applications that were accepted (if any). *Circle all that apply.*
GRE ~ GPA ~ Research experience ~ Recommendations ~ Reputation of CU
Other________________

What do you think were the key factors in the *rejection* of any of your applications (if any)? *Circle all that apply.*
GRE ~ GPA ~ Research experience ~ Recommendations ~ Reputation of CU
Other________________

Your job...

I am...	**Current**	**Past**	**Plan in future**
Employed in industry	☐	☐	☐
Employed in academia	☐	☐	☐
Employed in education	☐	☐	☐
In PhD program	☐	☐	☐
In terminal MS program	☐	☐	☐
Other __________	☐	☐	☐

I have a ___________ (highest degree)
in ________________ (field)

What is your job or degree program and who is your employer or school?

Is your job or degree program physics-related? ☐ Yes ☐ No

Are the <u>skills</u> you learned in your CU Physics degree applicable to your job or degree program? Please explain.

What were your <u>previous</u> jobs/degree programs (if any)?
1 (most recent) _____________________
2 _______________________________
3 _______________________________

My current main job or degree program is in *(check all that apply)*

- ☐ Acoustics
- ☐ Atomic or Molecular Physics
- ☐ Astrophysics
- ☐ Biological Physics
- ☐ Chemical Physics
- ☐ Computational Physics
- ☐ Condensed Matter Physics
- ☐ Engineering *What type?* ______
- ☐ Fluid Dynamics
- ☐ Geophysics
- ☐ History of Physics
- ☐ Instrumentation & Apparatus
- ☐ Laser Science
- ☐ Materials Physics or Processing
- ☐ Medical Physics
- ☐ Nanotechnology
- ☐ Nuclear Physics
- ☐ Optics
- ☐ Plasma Physics
- ☐ Polymer Physics
- ☐ Physics Education
- ☐ Other ________________

Two-semester courses....

Many of the courses offered by the physics department are two-semester courses -- for example, Electricity and Magnetism I and II. Sometimes both semesters are taught by a single instructor, and sometimes by two different instructors. Please reflect back upon your experience in CU Physics.

Which approach do you prefer?

- ☐ Same instructor for both semesters
- ☐ Different instructor for each semester
- ☐ It depends

Please elaborate:

Have you ever enrolled in a graduate degree program?

☐ **Yes** — **Please answer the remaining questions with respect to your graduate degree program, where applicable** (even if you are no longer enrolled)

☐ **No** — **Please answer the remaining questions with respect to your current job, where applicable.**

About Electricity and Magnetism 1 - Physics 3310

*Physics 3310 is the **FIRST** semester of the Electricity and Magnetism course, and required for majors. It is typically taken in the junior year. It includes electrostatics and magnetostatics, including Coulomb's Law, Gauss' Law, electric potential, the method of images, separation of variables, dielectrics, polarization, Ampere's Law, Biot-Savart Law, and magnetizeable materials. Mathematical techniques include solving partial differential equations, surface and line integration, vector calculus (div, grad, curl), approximations, and expansions.*

Do you remember.... The name of your instructor for this course? ______________

Your grade in the course (OPTIONAL)? ______________

The year you took the course? ______________

Describe at least one thing you remember about Physics 3310

What was the most valuable thing you learned in Physics 3310?

Did you mature as a physicist or student in this course? If so, how? If not, please elaborate.

Describe at least one thing you liked in Physics 3310, and which helped you learn.

Describe at least one thing you think could be improved in Physics 3310. (e.g., what would have helped you learn more? What do you wish had been covered?)

Any other comments?

I remember what I learned in Physics 3310

Strongly Disagree	1	2	3	4	5	Strongly Agree

I understood the material in Physics 3310

Strongly Disagree	1	2	3	4	5	Strongly Agree

I enjoyed Physics 3310

Strongly Disagree	1	2	3	4	5	Strongly Agree

Physics 3310 prepared me well to take the GRE (if applicable)

Strongly Disagree	1	2	3	4	5	Strongly Agree

Physics 3310 prepared me well for my job or graduate school

Strongly Disagree	1	2	3	4	5	Strongly Agree

I use something I learned in Physics 3310 in my life *outside* of my primary job or graduate research.

Strongly Disagree	1	2	3	4	5	Strongly Agree

I use the *physics* I learned in Physics 3310 in my primary job or graduate research

Strongly Disagree	1	2	3	4	5	Strongly Agree

If you agree, what physics do you use?

____

I use the *math* I learned in Physics 3310 in my primary job or graduate research

Strongly Disagree	1	2	3	4	5	Strongly Agree

If you agree, what math do you use?

____

I use the *problem-solving techniques* or approaches that I learned in Physics 3310 in my primary job or graduate research

Strongly Disagree	1	2	3	4	5	Strongly Agree

If you agree, what techniques do you use? ______________________________

Any comments on any of the above?

About Quantum Mechanics 1 - Physics 3220

*Physics 3220 is the **FIRST** semester of the Quantum Mechanics course, and required for majors. It is typically taken in the junior year. It includes the time-dependent Schroedinger equation (square wells and harmonic oscillators), eigenstates and eigenvalues, operator methods, scattering and tunneling in 1D potentials, orbital angular momentum, the hydrogen atom, and spin. Mathematical techniques include Hilbert space, solving partial differential equations, complex variables, Fourier analysis, and linear algebra such as matrices and commutation.*

Do you remember....	The name of your instructor for this course?	_______________
	Your grade in the course (OPTIONAL)?	_______________
	The year you took the course?	_______________

Describe at least one thing you remember about Physics 3220:

What was the most valuable thing you learned in Physics 3220?

Did you mature as a physicist or student in this course? If so, how? If not, please elaborate.

Describe at least one thing you liked in Physics 3310, and which helped you learn.

Describe at least one thing you think could be improved in Physics 3220. (e.g., what would have helped you learn more? What do you wish had been covered?)

Any other comments?

I remember what I learned in Physics 3220

Strongly Disagree	1	2	3	4	5	Strongly Agree

I understood the material in Physics 3220

Strongly Disagree	1	2	3	4	5	Strongly Agree

I enjoyed Physics 3220

Strongly Disagree	1	2	3	4	5	Strongly Agree

Physics 3220 prepared me well to take the GRE (if applicable)

Strongly Disagree	1	2	3	4	5	Strongly Agree

Physics 3220 prepared me well for my job or graduate school

Strongly Disagree	1	2	3	4	5	Strongly Agree

I use something I learned in Physics 3220 in my life *outside* of my primary job or graduate research.

Strongly Disagree	1	2	3	4	5	Strongly Agree

I use the *physics* I learned in Physics 3220 in my primary job or graduate research

Strongly Disagree	1	2	3	4	5	Strongly Agree

If you agree, what physics do you use?

____

I use the *math* I learned in Physics 3220 in my primary job or graduate research

Strongly Disagree	1	2	3	4	5	Strongly Agree

If you agree, what math do you use?

____

I use the *problem-solving techniques* or approaches that I learned in Physics 3220 in my primary job or graduate research

Strongly Disagree	1	2	3	4	5	Strongly Agree

If you agree, what techniques do you use? ______________________

Any comments on any of the above?

Thank you for your time!

Please return in enclosed envelope to: Stephanie Chasteen, 390 UCB, Boulder CO 80309

For more information, visit http://sei.colorado.edu

Or contact Katherine Perkins at
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