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Dr. Stephanie Chasteen

Dear Stephanie:

It is my pleasure to support Daniel Bolton's Physics 1140 transformation proposal. Physics 1140 or Experimental Physics 1 is a one-credit laboratory course that has not been changed in several years. The proposal is to have three faculty members (Daniel Bolton, Mike Dubson, and Heather Lewandowski) involved in transforming the course and launching its delivery in the Fall 2017 semester. Daniel Bolton will play a key role in purchasing equipment for the experiments and in writing manuals for the laboratory course.

I strongly support the Phys. 1140 course transformation plan. The budget request in the proposal has three months of summer salary for Dr. Bolton and funds his attendance at two conferences. Further there is a request to support 3 months of postdoc salary and to involve undergraduates. I feel this is a very reasonable request.

I wish to point out this is a strong faculty group who have experience in class transformation. In addition the expertise of the CU Physics Education Research group will be an invaluable resource in carrying out this work. I am also quite confident that the changes will disseminated to the broader physics community.

Sincerely,

John P. Cumalat

John P. Cumalat,
Professor of Distinction and Chair
Department of Physics
University of Colorado Boulder

1. Project title and person submitting

Title: Transformation of PHYS 1140: Experimental Physics 1
Person submitting: Daniel Bolton, Instructor, Physics, daniel.bolton@colorado.edu 2-7368

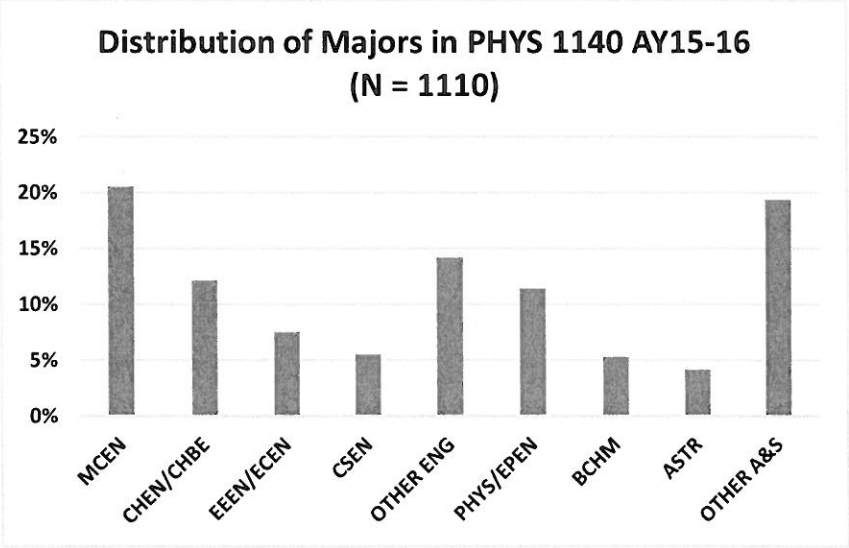
2. Courses to be changed and rationale

Laboratory courses offer significant opportunities for engagement in the practices and core ideas of science. Laboratory course environments typically have extensive lab equipment, flexible classroom arrangements, low student/teacher ratios, and opportunities for collaborative work that promote students' engagement in a range of scientific practices (e.g., asking questions, designing and carrying out experiments, analyzing data, developing and refining models, and presenting results to peers). Creating such opportunities requires significant investments in physical space, sophisticated equipment, and instructor support. Despite the abundant opportunities and resources in many laboratory courses, concerns are frequently raised about how effective such courses are at fulfilling their potential.[1-4] There are many calls to transform lab courses coming from the physics education community,[5-7] the community of laboratory instructors,[8] as well as national science policies promoting the retention of STEM majors and the development of the STEM workforce.[3] In particular, the American Association of Physics Teachers recently adopted the "Recommendations for the Undergraduate Physics Laboratory Curriculum",[9] where one of the PHYS 1140 project leaders was an author. The physics department at CU is a leader in physics education in both the introductory lecture courses, as well as in upper-division lecture and lab courses. However, there is one very important and yet untouched area, the introductory lab course, PHYS 1140.

PHYS 1140: Experimental Physics 1 is a one-credit lab course, which is most often taken concurrently with PHYS 1120 General Physics 2 (calc-based intro. physics). During the 2015/2016 academic year, it served over 1110 students in a wide variety of majors, with a majority of students coming from the College of Engineering and Applied Science (CEAS) (Fig. 1). It is the only physics lab course most of these students will take, and hopefully serves the role of introducing students to authentic physics experimentation. As the physics department continues to evaluate the quality of instruction at various levels, PHYS 1140 has come to our attention as requiring an overall transformation to increase the learning to meet expectations.

Over the last four years, we have been gathering data on student performance and satisfaction with this course. These data include responses to a nationally validated attitudes and beliefs survey developed by CU's Physics Education Research (PER) group. The Colorado Learning Attitudes about Sciences Survey for Experimental Physics (E-CLASS) shows that students' beliefs about the nature of physics experimentation shifts to more novice views after instruction, which is not an uncommon, but definitely an undesirable, outcome. In addition to this survey, the CEAS administers several surveys during and after their students' career at CU for ABET accreditation. In the recently administered spring 2016 Mid-Curriculum Survey, many students expressed concerns about PHYS 1140, including complaints about busy work, the amount of work required for the credit received, uncertainty as to the point of the course, and a feeling that there was no value gained from the course. These concerns have been also reported in Senior Surveys, indicating that students retain unfavorable memories about this course even several years after taking it. Overall, we have evidence that PHYS 1140 is not meeting the bar for educating our students, and thus we must take action to dramatically improve the course.

We are proposing to use a research-based approach to transform PHYS 1140 into a nationally leading example of excellence in introductory laboratory instruction. This will have many benefits to the students who take the course, the science and engineering departments that rely on the course to educate their students in experimental methods, and to CU's reputation as place for excellent education in physics.



3. Course Development Plan

a. Timeline

Spring 2016: Creation of Consensus Learning Goals

1. We reached out to CEAS leadership and requested input from their faculty. CEAS responded by putting together a committee with broad representation across the college. Representatives from this committee attended most of our meetings during the Spring 2016 semester. Terry Mayes created and distributed a survey to all CEAS faculty asking for input on PHYS 1140. We received over 90 responses.
2. We developed a set of open-ended questions aimed at uncovering expert's opinions about the learning goals of an ideal introductory lab course. We broadcasted a call to all physics faculty to participate in a 30-minute individual interview.
3. Mike and Daniel performed 10 individual interviews with physics faculty, one staff member, and one former student.
4. We drew common themes, as well as areas of disagreement, from the individual interviews and created a plan for a series of faculty round-table discussions.
    a. Round-table 1: We discussed the inclusion of uncertainty as a learning goal and began to discuss the role of computing in the course. Approximately 10 faculty members attended this meeting.
    b. Round-table 2: We discussed whether scientific writing and presentation of data should be learning goals. Approximately 10 faculty members attended this meeting.

c. Round-table 3: We reviewed consensus learning goals, discussed how experimental design will be included, and discussed which physics topics should be present in the course. Approximately 8 faculty members attended this meeting.

5. The outcome of the work done during the Spring 16 semester was a set of learning goals and guiding principles (See Section 3b).

Summer 2016: Secure Funding and prepare for Fall 2016

1. We wrote a proposal to secure funding for the project. The proposal was submitted to the College of Arts & Sciences and to the College of Engineering and Applied Sciences. Although both have agreed to contribute, details and final approval are still pending.
2. Heather prepared to teach PHYS 1140 for the first time in its current, non-transformed state.

Fall 2016/Spring 2017: Data Collection/Analysis and Development of New Course Structure

1. Heather will collect extensive baseline data in her PHYS 1140 courses to understand the current state of the course and level of student learning. The data sources include E-CLASS, FCQs, course artifacts, classroom observations, and the Physics Measurement Questionnaire.
2. We will design a new lab structure and course environment for a transformed PHYS 1140 based on our learning goals and information learned from the analysis of assessment results. This will include:
    a. We will rethink how to use the lecture time.
    b. We will design a new course structure, which includes what students will be graded on and what artifact they will create.
    c. We will design experimental activities that attempt to have students meet our learning goals.
    d. We will design general procedures and tabulate equipment needs to support experimental activities.
3. Heather will supervise a postdoctoral research associate's work. The postdoc will manage data collection and perform the qualitative coding analysis and statistical analysis on the data collected during AY16/17. The postdoc already has extensive experience in qualitative coding of these types of data.
4. Daniel will search for and hire an undergraduate student (one or more, to be determined) to assist in implementation during Summer 2017.

Summer 2017: Creation and Testing of new Experiments

1. Daniel and his team will design laboratory experiments, order, and assemble equipment. Michael will provide assistance as needed.
2. Daniel will write lab manuals, TA instructor guides, and ancillary computer software with assistance from Michael as needed.
3. Daniel will pilot the new labs with summer sections of PHYS 1140 and with his undergraduate(s).
4. Daniel will attend the Summer Meeting of the American Association of Physics Teachers to gather and share ideas with other universities.

Fall 2017: Full Course Implementation and Data Collection

1. Heather will teach the transformed version of the course for the first time.
2. Heather will collect extensive data in her PHYS 1140 course to evaluate the changes made to the course. The data sources include E-CLASS, FCQs, course artifacts, classroom observations, and the Physics Measurement Questionnaire.
3. Heather will supervise a postdoctoral research associate's work. The postdoc will manage data collection and perform the qualitative coding analysis and statistical analysis on the data collected during Fall 2017. *Results from the analysis will inform further iterative changes to the course* and will be used in peer-reviewed publications.

b. Leadership plan

Heather Lewandowski, *Associate Professor and Associate Chair of Physics, Director of the Engineering Physics Program, and JILA Fellow*. Heather currently leads two research programs, one in atomic molecular and optical (AMO) physics, and the other in physics education research. Her AMO research efforts focus on creating and studying interactions of cold, chemically important molecules for the interstellar medium. Her PER program studies ways to increase students' proficiency with scientific skills such as using model-based reasoning, troubleshooting, and scientific communication in experimental physics. She has led efforts to successfully transform both of CU's upper-division physics lab courses (Electronics and the Advanced Lab) over the last five years with the support of NSF funding. Heather will lead the education research portion of the project including collecting and analyzing all data, serving as the mentor for the PER postdoc, and coordinating efforts among team members.

Michael Dubson, Senior *Instructor and Associate Chair for Undergraduate Studies, Physics Department.* Michael often teaches the large freshmen courses, PHYS1110 and PHYS1120, and he has taught PHYS1140 in the past. He was involved in the last overhaul of the course way back in 1995. He is a member of the Physics Education Group, and is involved in 3 areas of educational reform: He is a software developer for PHET, which produces the world's most popular science education software. He works Prof. Steven Pollock, producing curricular materials for reformed upper-division courses. And he works with Prof. Noah Finkelstein, studying the pedagogical effectiveness of online courses. His training and background is in condensed matter experiment, and he has extensive experience in writing curricular materials including laboratory manuals, tutorial activities, and clicker questions. He will be working with Dr. Bolton on the implementation phase of the project.

Daniel Bolton, *Instructor of Physics*. Daniel is one of the department's two full-time instructors and regularly teaches PHYS 1110 and 1120 (the first-year introductory lecture sequence that most PHYS 1140 students take). Daniel has recently taken over leadership of the department's Learning Assistant program. He also recently implemented an overhaul of the department's undergraduate research programming, introducing a new website, information session, and poster session. His research area is theoretical nuclear physics and he currently mentors two undergraduate students. Daniel will be primarily responsible for the implementation phase of the PHYS 1140 project: purchasing equipment, writing manuals, and working with students to test out labs.

c. Assessment plan

During Spring 2016, a series of interviews and round-table discussions resulted in a set of consensus learning goals and assessment instruments.

1) Students' epistemology of experimental physics should align with the expert view
    a. *Alternative Definition:* Student's beliefs about the nature of experimental physics should align with expert physicists. This includes understanding that physics is an experimental science, what makes for a valid measurement, and how knowledge is gained through experiments.
    b. *Assessment*: E-CLASS epistemology items
2) Students should have a positive attitude about the course
    a. *Assessments*: FCQ's with additional tailored questions
3) Students should have a positive attitude about experimental physics
    a. *Assessments*: E-CLASS affect items + new questions about exp. physics
4) Students should be able to make a presentation quality graph showing a model and data
    a. *Assessments*: course artifacts
5) Students should demonstrate a set-like reasoning when evaluating measurements
    a. *Alternative Definition*: Students should understand that a measurement has an associated uncertainty and is not the "true" value. They should understand that repeated measurements form a distribution with a mean and a standard deviation.
    b. *Assessment*: Physics Measurement Questionnaire (validated assessment developed at Cape Town)

In addition to assessing our learning goals, we will use the CEAS surveys and Senior Surveys to measure our success.

d. Faculty & instructor involvement

Heather, Michael, and Daniel are all making significant investments to this project, as detailed throughout this proposal. Heather's effort is germane to her teaching assignment (she is teaching PHYS 1140 three semesters in a row to support the project). She also expects to publish the results of this project. As a Senior Instructor and the Associate Chair for Undergraduate Studies, Michael is directly invested in increased student satisfaction with PHYS 1140. As an Instructor, Daniel is also invested in all Departmental efforts to forward teaching. We are proposing that Daniel will be paid Summer salary to enact the details of the transformation.

e. Sustainability

In the Physics Department, different faculty members teach PHYS 1140 each term. Although sometimes a faculty member will teach the course several times in a row (as Heather is doing now), in general the course rotates through everyone's hands. It is therefore of the utmost importance that this transformation course is sustained ***without*** regular, direct effort by Heather, Michael, and Daniel. If it is

easy and/or desirable for a random faculty member to "revert" to the current course, then this project's impact will be greatly diminished. We decided on three primary means to achieve this end.

1) We involved the whole department in the creation of learning goals during Spring 2016. All physics faculty were invited for individual interviews and three round-table discussions followed.
2) We hope to design a TA training protocol that involves permanent staff members who will become intimately familiar with the transformed course.
3) The transformed version of 1140 will be designed in a way that makes it practically difficult to "revert". Timing of lab sections, available materials, etc. will all encourage faculty members to stick with the transformed version of the course, if for no other reason, because it will be easier to do so.

Finally, it is important to note that, as Instructors, a primary part of Michael's and Daniel's job is to support faculty teaching in the department. They will always be available to help and it is understood that this is part of their workload at CU.

f. Coordination across the department

Increased understanding of the meaning of uncertainty will directly affect student's experiences in the upper-level physics lab courses, 2150, 3310, and 4430. At the same time, a de-emphasis of error-propagation (as dictated by our consensus learning goals) will require this topic to be covered in subsequent courses. We have attached a letter of support from the Chair of the Physics Department.

4. Broader impacts

The central purpose of this project is to enact a sustained transformation of PHYS 1140 that will persist indefinitely. As faculty are assigned to teach PHYS 1140, they will be taught by Michael and Daniel (in their support roles as instructors) as well as by the prior 1140 instructor, how to run the transformed course. It is hoped that the experience of teaching a transformed course will then encourage the faculty member to enact similar transformations in other courses.

5. Evidence of expertise

Heather has extensive experience with large-scale course transformation and is actively involved in Physics Education Research at CU. She has led NSF funded upper-division lab course transformations in recent years. Michael has extensive experience in writing curricular materials. He was the original designer of the current curriculum for PHYS 1140. Daniel's experience in large-scale course transformation is minimal, but he is very familiar with active learning and student-centered pedagogy through his use of Physics Education Research in teaching introductory physics. Working on this project will dramatically increase Daniel's experience in course transformation and will make him more valuable to the department as an agent of change.

6. Resources requested

a. Budget

We are requesting funds to support the effort to develop a new course structure and course materials, to measure the level at which students are achieving the learning goals both before and after the transformation, and to purchase equipment required to meet the new goals. We suggest the costs be shared by the physics department (through income from course fees), TRESTLE, and the College of Arts & Sciences with possible input from the CEAS. Completely transforming any course takes considerable resources and lab courses even more so. However, the positive impact of the effort will also be large. We include the entire budget below, and propose that TRESTLE support go toward Daniel's summer salary.

Item	Semester	Direct Cost	Benefits
Summer Salary (3 Months), D. Bolton	Summer 2017	$18,000	+ benefits
Two conferences, D. Bolton	Feb 2017 and Su. 2017	$3,000	
PER Postdoc Salary (2 Months)	Fall 2016/Spring 2017	$9,000	+ benefits
PER Postdoc Salary (1 Month)	Fall 2017	$4,500	+ benefits
Undergraduate (Dept.) (40 hours x $10 x12 weeks)	Summer 2017	$4,800	
Equipment Costs (College)	Summer 2017	$60,000	
Equipment Costs (Dept.)	Summer 2017	$60,000	
	Total from College	**$94,500**	**+ benefits**
	Total from Physics Dept.	**$64,800**	

b. Non-financial resources requested

Daniel expects to take advantage of Stephanie's "Shindig" group to discuss this project. It would also be very helpful to consult with CSL educational advisors as questions/needs arise.

7. Resources leveraged

As detailed in our budget, we are expecting to leverage significant support from the Physics Department, the College of Arts & Sciences, and the CEAS.

8. Agreement to expectations

We understand and agree to these expectations.

References

[1] R. Trumper, "*The Physics Laboratory: A Historical Overview and Future Perspectives*," Science & Education **12** (7), 645-670 (2003).

[2] Avi Hofstein and Vincent N Lunetta, "*The laboratory in science education: Foundations for the twenty - first century*," Science education **88** (1), 28-54 (2004).

[3] Steve Olson and Donna Gerardi Riordan, "*Engage to Excel: Producing One Million Additional College Graduates with Degrees in Science, Technology, Engineering, and Mathematics. Report to the President*," Executive Office of the President (2012).

[4] Carl Wieman and N. G. Holmes, "*Measuring the impact of an instructional laboratory on the learning of introductory physics*," American Journal of Physics **83** (11), 972-978 (2015).

[5] American Association of Physics Teachers, "*Goals of the Introductory Physics Laboratory*," Am. J. Phys. **66** (6), 483-485 (1998).

[6] Benjamin M. Zwickl, Dehui Hu, Noah Finkelstein, and H. J Lewandowski, "*Model-based reasoning in the physics laboratory: Framework and initial results*," Physical Review Special Topics - Physics Education Research **11** (2), 020113 (2015).

[7] N. G. Holmes, Carl E. Wieman, and D. A. Bonn, "*Teaching critical thinking*," Proceedings of the National Academy of Sciences **112** (36), 11199-11204 (2015).

[8] Advanced Lab Physics Association, http://www.advlab.org/

[9] AAPT Recommendations for the Undergraduate Physics Laboratory Curriculum, https://www.aapt.org/Resources/upload/LabGuidlinesDocument_EBendorsed_nov10.pdf