

# Issues and Progress in Transforming a Middle-division Classical Mechanics/Math Methods Course

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**Abstract.** The physics department at the University of Colorado, Boulder has recently begun the transformation of its Classical Mechanics/Math Methods course, a middle-division course taken primarily by sophomore physics majors. We discuss the process of course transformation, including holding faculty meetings to create consensus learning goals and a conceptual diagnostic, and adopting, adapting and creating course materials and structures. We also report preliminary observations of student learning gains, student attitudes towards the transformation, and common student difficulties with the course material. We also discuss ongoing plans for the course transformation.

**Keywords:** physics education research, course reform, classical mechanics, math methods, assessment

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## INTRODUCTION

The physics department at the University of Colorado (CU) has transformed many physics courses to make use of instructional techniques shown to improve student learning. Introductory courses in the department have included interactive techniques since 2003. More recently, as part of the Science Education Initiative, the department has transformed upper-division Quantum Mechanics and Electricity and Magnetism.[1,2] These transformations have received positive feedback from both students and faculty and have improved student learning.[3,4] However, there are middle-division courses that have still mainly been taught using traditional lecture. Additionally, instructors in the upper-division courses often complain that students lack the prerequisite math skills for these courses. The department therefore decided to transform the first semester of its combined two-semester Classical Mechanics/Math Methods sequence (PHYS 201).

At CU, PHYS 201 is typically taken starting the second semester of the sophomore year and enrolls 35-75 students. This course serves as a bridge from introductory physics courses to upper-division courses, and is often among the first physics courses students take that involves long calculations in homeworks, and the need to connect mathematical and physical knowledge to solve problems.

In this paper we describe the progress we have made in transforming this course. We first discuss the process, including the creation of consensus learning goals and a conceptual post-assessment, as well as a discussion of which course elements changed. We then discuss some preliminary results of this

transformation, including observed student difficulties, exam and conceptual-post test results, and student attitudes towards the changes.

## THE TRANSFORMATION PROCESS

Over the past 2 years, we have begun the process of systematically improving PHYS 201 based on research. The first step was learning about the current course and common student difficulties. This was achieved by having a postdoctoral Science Teaching Fellow (STF) sit in on a semester of the traditionally taught course and hold homework help sessions. These observations were followed by faculty meetings to determine course learning goals and topical coverage and to create a conceptually focused post-assessment. Following the semester of observation, the course pedagogy and materials were modified for two semesters with iterative improvement between semesters. Below we discuss each of these steps of course transformation.

### Learning Goals and Topical Coverage

The first step in our transformation process was to determine topical coverage and create consensus-learning goals for the course, which later guided the rest of the course transformation. More details of this process are described in Pepper *et al.*[5] Because the course content fluctuated between semesters, the faculty first determined a consensus about what the course should include. They decided it should be focused slightly more on math methods than classical mechanics, but that the math should be taught in a physics context (that could sometimes be outside

classical mechanics). There was a surprisingly strong consensus on which math methods to focus on in this course. Some of these are: Taylor series, Fourier series, solving first order ODEs with constant coefficients, and solving PDEs with separation of variables. Faculty also determined broad course-scale learning goals, such as “students should be able to justify the reasonableness of a solution they have reached, by methods such as checking the symmetry of the solution, looking at limiting or special cases, relating to cases with known solutions, checking units, dimensional analysis, and/or checking the scale/order of magnitude of the answer.”[1,2] Faculty then modified a list of topical learning goals provided by the STF, such as “Students should be able to derive the relevant separated ODEs in Cartesian coordinates from Laplace’s equation.” All course material, including learning goals are available online at [www.colorado.edu/sei/departments/physics\\_2210.htm](http://www.colorado.edu/sei/departments/physics_2210.htm).

### CCMI Post-Assessment Development

Because traditional exams often do not assess the skills and concepts listed in the learning goals, we developed the Colorado Classical mechanics/Math methods Instrument (CCMI) to address some of the most fundamental learning goals. These fundamental goals were determined by the faculty in a set of four meetings. The CCMI has been administered for two consecutive semesters at CU, as well as to a similar course at another institution. Feedback was provided both to individual students (about their performance in different topical areas), and to the course instructor (about overall course performance). The instrument has been evaluated and improved between each administration, and student interviews have been performed. The assessment currently consists of fourteen open-ended questions and two multiple-choice questions. Students scored  $46\pm 2\%$ ,  $55\pm 3\%$ , and  $63\pm 3\%$  in the three courses we have administered it (errors and error bars reported in this paper are standard error on the mean), with the lowest scoring question having an average among CU students of 10% and the highest an average of 91%. We are currently meeting with members of the CU physics faculty in order to shorten the diagnostic to fit in one 50-minute period. Once shortened, questions will be validated using student interviews, and the test as a whole will be analyzed for validity and reliability. We also plan to investigate whether making the test mostly multiple-choice (for ease of grading) can still serve to assess our learning goals effectively.

### What Changed

In many ways the course transformations were more evolutionary than revolutionary. The course was still primarily a lecture course with several student-centered interactive components added as described below. During the process of course transformation additional instructors – an STF and sometimes an undergraduate learning assistant (LA) – were available both in and out of the classroom to facilitate activities.

**Lecture Techniques and Clickers:** One of the changes we made was to add clicker questions with peer instruction[6] to lecture. Typically between 3 and 8 questions were asked in each 75-minute class. They were intended to be difficult conceptual questions that students would need to discuss with their neighbors in order to answer. Some open-ended or calculational problems were also asked. For nearly all questions, small-group discussion was followed by a brief whole-class discussion and wrap-up.

**Tutorial in Class:** Beyond the short interactive intervals provided by clicker questions and interactive lecture, we also added longer periods of small-group work, guided by a conceptually focused worksheet. These activities lasted 10 to 50 minutes. We primarily adopted or adapted tutorials from the Intermediate Mechanics Tutorials available at <http://perlnet.umaine.edu/jmt/>[7], though we also authored a few new activities.

In our previous course transformations at CU, tutorials appeared in a section separate from the course, which allows for more lecture time, but has lower attendance than lecture and takes more faculty time. We found several advantages to having the tutorial during the main course lecture period. Students who might not have joined an optional section did attend class. We could also integrate the activities with the lecture, and switch between lecture, clicker questions, and tutorial to create a cohesive learning experience for a particular topic.

**Homework Assignments:** We found that typical textbook problems did not target all of the essential learning goals for our course. Solutions to textbook problems are also available online. We therefore created new problems (often modified versions of textbook problems) to include sense-making and expectation-checking, visualization and sketching, and use of *Mathematica*.

**Homework Help Sessions:** To make the course more student-centered and to increase peer-peer interactions we replaced traditional office hours with two hours of

small-group homework help session. In these sessions, students worked with each other in groups of 2-5 to solve homework problems with the instructor available, playing the role of Socratic questioner.

**Online Conceptual Reading Quizzes:** We added weekly online conceptual reading quizzes (graded solely on participation) based on “preflights” adapted from Gregor Novak and Steven Novotny at the U.S. Air Force Academy[8]. We also added questions asking students to explain in their own words steps from example problems or derivations in the book, and to ask us lingering questions about the reading. These reading quizzes allowed the instructor to target confusing parts of the reading during lecture. The instructor also answered select individual student’s questions both online and by e-mail so that students knew that someone was reading their quizzes.

## RESULTS

While our transformation is still in progress, we report some preliminary results of student difficulties, learning gains, and attitudes toward the transformation.

### Student Difficulties

Throughout the process of course transformation, we have had opportunities to observe student difficulties with the PHYS 201 topics during clicker questions, tutorial, and help sessions, as well as in a few preliminary student interviews. Below we list a few difficulties we have observed, but note that they are preliminary observations which we intend to support further in future publications.

One topic that we find some students have consistent difficulties with throughout the semester is Taylor series. Students seem to struggle to understand the benefit of replacing an exact function with an approximation and also struggle to decide when it is appropriate to use a Taylor expansion. Once they have decided to use a Taylor expansion, they further have difficulty identifying an appropriate small parameter to expand in, deciding which part of a function should be expanded, and deciding what point to expand around (usually but not always zero in physics).

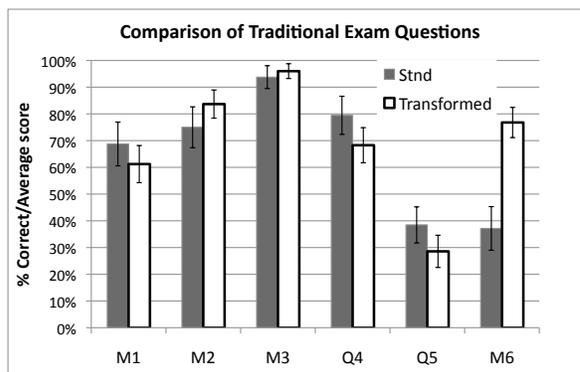
Students also seem to have difficulty checking their answers. While through the course of the semester many students mastered checking the units of their final answer, most students still struggled to use limiting cases as a check. Students seemed not to understand the logic of the check – i.e. that they needed to have an expected answer in the limit before calculating what their answer was in that limit.

Students also seem to have difficulty using initial conditions to solve ODEs. Some students do not realize that having two unknown constants is problematic, and many seem not to be able to translate problem phrasing such as “an object starts at rest at  $t=0$ ” into a velocity initial condition.

## Learning Gains

Preliminary results of the CCMI show that students struggle with the concepts from this course, but that our approach to improving instruction seems to be working. For instance, after the first implementation of the transformed course, we noticed that students were having difficulty deriving separated ODEs from Laplace’s equation, and designed a lecture combining clicker questions, short tutorial sequences, and whole-class discussion to address this difficulty. On a CCMI question targeting this learning goal, students in the first cycle of the transformed course scored  $45\pm 11\%$  while in the second iteration (with the new activities) students averaged  $72\pm 9\%$ . The CCMI has not yet been administered in any CU course taught in a standard manner, so cannot yet tell us directly how effective the transformations are compared to standard lectures.

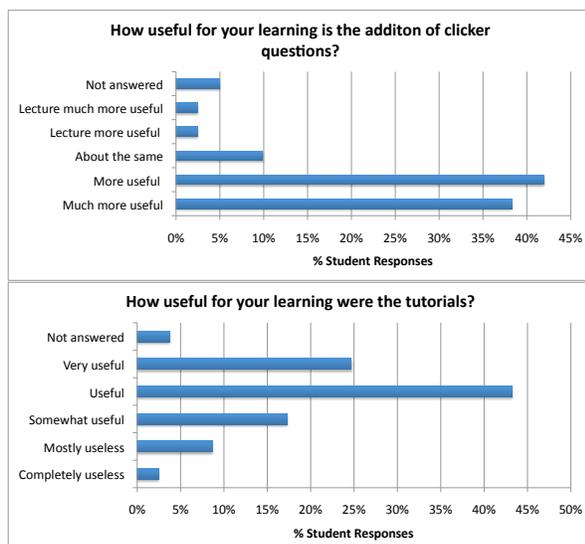
In transformed classes, there is a concern that devoting a larger fraction of time to concepts may negatively impact students’ computational abilities. To examine this issue, we have administered some common midterm and final exam questions between standard and transformed courses. These questions were then re-graded by one of the authors (REP) on a common rubric (Fig. 1). Students in the transformed and standard courses perform comparably, with some questions having stronger performance for traditionally-taught students and some for students taught with the transformed pedagogy.



**Figure 1.** A comparison of student performance on midterm and final exam questions given in common to standard and transformed courses. “M” indicates a multiple choice question, while “Q” indicates long answer. Numbers 3-6 were all computationally focused.

## Student Attitudes

Some faculty worry that physics majors may feel condescended to by transformed pedagogy. We find the opposite: students appreciated the transformed pedagogy as determined by an end-of-semester survey given after each implementation of the transformed course. Clicker questions were one of the most popular aspects of the course transformation. One student commented that “they [the clicker questions] required you to make the step from simply agreeing with the professor to having figured it out yourself, which makes remembering (and comprehending) much stronger.” Overall 80% of students in the two transformed semesters thought that the clickers were “more useful” or “much more useful” than pure lecture without clickers. For a breakdown of student responses to this question, see Fig. 2.



**Figure 2.** Combined results from the end-of-semester student survey asked online to two semesters of students in transformed courses. N=81.

Students also felt positive about the addition of tutorial to lecture. Overall 68% of students thought that the tutorials were “useful” or “very useful” for their learning. A breakdown of student responses is provided in Fig. 2. One student commented that the tutorials were “helpful because we actually were actively thinking in class and talk over/explaining things to other students... It’s easy in a normal lecture to just sit there and follow the work on the board and not engage your mind.”

Students were less enthusiastic about reading quizzes; some said that they felt it was busy work and that they didn’t have to read the whole assigned reading in order to answer questions. Overall 32% of students thought that the reading quizzes were “useful”

or “very useful” for their learning and 30% thought the reading quizzes were “somewhat useful” (N=44).

## CONCLUSIONS & ONGOING PLANS

In three semesters of work on PHYS 201 we have succeeded in creating consensus learning goals (both topical and course-scale), and a preliminary conceptual post-test. We have changed the course to make it more student-centered and interactive, including adding clicker questions and peer instruction, tutorial activities in class, non-computational tasks to homework problems, homework help sessions, and online conceptual reading quizzes. Through this process we have been learning about common student difficulties with the material, and have discovered that students like the changes we have made to the course.

We have gone through one successful iteration of improvement to the course and its materials based on feedback from the first semester. We plan to continue our process of systematic improvement for at least two further semesters as we learn more about student difficulties and continue to get feedback from students and instructors. Updated versions of all materials we develop will be available at [www.colorado.edu/sei/departments/physics\\_2210.htm](http://www.colorado.edu/sei/departments/physics_2210.htm).

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