

Documenting the conversion from traditional to Studio Physics formats at the Colorado School of Mines: Process and early results

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Abstract. The Colorado School of Mines (CSM) has taught its first-semester introductory physics course using a hybrid lecture/Studio Physics format for several years. Over the past year we have converted the second semester of our calculus-based introductory physics course (Physics II) to a Studio Physics format, starting from a traditional lecture-based format. In this paper, we document the early stages of this conversion in order to better understand which features succeed and which do not, and in order to develop a model for switching to Studio that keeps the time and resource investment manageable. We describe the recent history of the Physics II course and of Studio at Mines, discuss the PER-based improvements that we are implementing, and characterize our progress via several metrics, including pre/post Conceptual Survey of Electricity and Magnetism (CSEM) scores, Colorado Learning About Science Survey scores (CLASS), solicited student comments, failure rates, and exam scores.

INTRODUCTION

The need for research-based improvements to instruction in STEM disciplines is well-known,¹ and PER has generated a plethora of options. Some reforms have extended to complete restructuring of the physical instructional and learning environment in addition to refinements of pedagogy and curriculum, with successful models including Studio Physics,² TEAL,³ and SCALE-UP.⁴ These approaches aim to teach physics with most or all of the contact time taking place in a room designed to facilitate interactive engagement: the Studio.

The Colorado School of Mines (CSM) has for several years had the first semester of its introductory sequence (Physics I) taking place in a Studio environment. In the past year, we have been converting Physics II, the second semester of calculus-based physics, to a Studio format. This process has been guided both by our experience with Physics I and by innovations made by a number of PER groups. One of our goals has been to study and document the conversion process in sufficient detail to identify factors contributing to and impeding success, in order to maximize our own effectiveness and to inform other similar transitions. In this paper, we present an overview of Studio physics at CSM, one potential model for transitioning from traditional to Studio physics, and early data describing this transition. Since implementing Studio Physics can be very demanding in terms of resources and time, a key focus is developing a model that reduces this load to whatever degree possible.

STUDIO PHYSICS AT CSM

CSM is a public university located in Golden, Colorado, serving approximately 4000 undergraduates. The school offers science and engineering majors almost exclusively, and all students take the same core of math and science courses. This core includes Physics I and Physics II, the first and second semesters of introductory calculus-based physics.

In the mid 1990s, CSM constructed a cross-departmental Center for Technology and Learning Media (CTLM) building, and the department successfully lobbied for the creation of a Studio room in that building (Figure 1). Sections of Physics I were immediately converted to a hybrid Studio format including two one-hour lectures per week, and two two-hour blocks of Studio time. Retaining a lecture component in the course, rather than switching to a total Studio mode, reduces load on the Studio facilities and has also aided acceptance from more traditional elements of the institution.⁵ This mode strongly connects lectures and Studios: Course material can be separated into two-day blocks, where new principles are introduced in the lecture in one day, and students study applications the next day in the Studio.

Studio Physics I resulted in significant student progress, with Force Concept Inventory⁶ (FCI) gains on the order of 50%, compared to 20-25% pre-Studio. Also, student surveys, course evaluations, and exit interviews demonstrate greater student satisfaction with the Studio than with the traditional format.⁷ For several years, space and personnel constraints required Physics II to stay in a traditional format, despite student



Figure 1: The Physics Studio at CSM (top). A student group working in the Physics II Studio (bottom).

dissatisfaction with it after exposure to the Studio format in Physics I. Recently these constraints lifted, and in the summer of 2007 we began the initial conversion process to conduct Physics II in the Studio format, using the same basic structure as Studio Physics I.

COURSE DEVELOPMENT

In the first year of Studio Physics II, we have retained much of the curriculum from the traditional course. Many activities from former labs and recitations now occupy the Studio time slots. This transference-without-update has allowed us to implement Studio over a short timeframe, but leaves many needs for future developments.

While the Studio transformation is incomplete, several research-based course changes have been piloted based on our experiences with Physics I. Among these is the restructuring of student groups in Studio. These groups have three people whenever possible, with a member from each of the top, middle, and bottom thirds of the Physics I course, as determined from the final course grades.⁸ This group configuration allows the weaker students to get assistance from the stronger, and allows the stronger to learn by teaching.⁸ We have also attempted to circumvent any potential gender- and culture-related

difficulties in group interactions. Any group that has any female members has at least two, and any group that has any international students or students from traditionally underrepresented populations has at least two. This membership structure has been observed to significantly increase engagement among all students and to facilitate favorable group dynamics. Anecdotally, these group assignments have resulted in more consistent performance across the Studio in Physics II as compared to the randomly generated groups used in Physics I.

With the switch to group work, we need more challenging and compelling Studio problems. Many of the problems currently posed as homework or Studio activities are "end of the chapter" style, involving equation manipulation with little context. While developing applied math skills is a major goal of the intro physics sequence, it is well-established that problems involving modeling, estimation, and more authentic contexts can significantly increase interest and performance.⁹ Our primary model will be an adaptation of the Context-Rich problems initially developed by the PER group at the University of Minnesota.¹⁰ An ideal Context-Rich problem involves several key features: 1) it is challenging enough that a single student cannot solve them, but not so challenging that a group cannot solve them; 2) it is structured so that the groups can make decisions on how to proceed with the solution; 3) it is relevant to the lives of the students; and 4) they do not depend on the students knowing a trick. In Figure 2, we show a typical problem from the current problem-solving Studio curriculum along with a problem that develops the same ideas using some Context-Rich principles.

The introduction of Context-Rich problems represents an improvement to the *content* of the activities in our curriculum, but we also need to address the *structure* of these activities. We have recently begun applying an adaptation of the Cognitive Apprenticeship model¹¹ to the material used in the Studio sessions. We model a problem-solving process during lecture, coach the students through the process during the Studio sessions while they work on the problems, and add scaffolding to the more difficult group problems that is then progressively removed until students are left with problem statements alone. This gradual removal of scaffolding has been shown in other contexts to aid students in learning particularly challenging material.¹² The problem in Figure 2 shows an example implementation of this scaffolding. This structure is relatively easy to implement using online content delivery systems, in this case LON-CAPA.¹³ Problem parts are revealed in sequence as earlier parts are completed.

Our Studio sessions also feature a variety of hands-on activities and experiments to complement the

Uniformly Charged Sphere

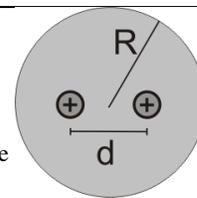
A nonconducting solid sphere of radius 2.30 cm carries a uniform positive charge of 7.4 nC.

Calculate the magnitude of the electric field at a point 1.9 cm away from the center of the sphere.

Figure 2. A traditional problem from the current Physics II Studio (left), and an updated problem covering the same topic with elements from Context-Rich problems and problem scaffolding (right).

The H₂ Molecule

A very simple (but still somewhat effective) model of the hydrogen molecule includes two positive point charges separated by some distance d , and a concentric negative charge distribution of radius R . Use this model to find the equilibrium covalent bond length d .



a) First, choose one of the positive charges. It will be in equilibrium when the forces on it total zero. Draw a free body diagram that identifies all of the forces on this charge.

b) Now calculate the force on your charge due to the presence of the other positive charge.

c) Use Gauss's Law to determine the force on the charge due to the electron cloud. Hint: What is the electric field created at that location by a uniform spherical charge distribution?

d) Equate these forces to obtain an algebraic expression for d .

problem solving. Some of these also carry over from the traditional curriculum, which featured both stereotypical verification-style labs and more design-based labs, such as one in which students design, build, and test a simple metal detector. We are replacing the less successful, more “cookbook” activities with activities drawing on several sources. Some of these are investigative, using simple equipment to answer questions about physical systems and discover relationships. Others use research-based simulations such as Physlets and the PhET sims.^{14,15} Still others involve building and testing simple devices, in the style of the metal detector lab. Our goals here are to make Studio more engaging and more representative of what these engineering students will encounter in a professional environment.

DATA

We have been collecting a variety of quantitative and qualitative data on Physics II for several years, including the Conceptual Survey of Electricity and Magnetism (CSEM)¹⁶ and the D/Fail/Withdraw (DFW) rates. Starting in the fall of 2007, we expanded this coverage to include the CLASS attitude survey.¹⁷ In Figure 3, we show the results of these instruments. The dotted line indicates the transition from traditional to Studio. CSEM normalized gains have averaged 39% over the past three years ($N \sim 300$ -400 per semester) with no clear trend up or down. The DFW rate appears to be dropping, though this is not yet clearly attributable to Studio. The CLASS attitude shifts are neutral, generally considered to be a positive result for an introductory course.¹⁸

In the Spring of 2008, we gave students a magnetism exam that was identical to that given in the Spring of 2007. This enabled a direct comparison of Studio to traditional performance without time-of-year

population effects (the spring and fall Physics II populations differ considerably). The pre-CSEM percentages of the two groups were statistically similar. The exam had a multiple-choice (80% of the exam score) and a long-answer section. Performances on the long answer section were identical. The Studio group outperformed the traditional group on the multiple choice section by 70% to 63%, significant at a $p < 0.0001$ level using a two-tailed z-test.

On a qualitative level, student response to Studio on course evaluations (including both university evaluations and our own in-course surveys) has been overwhelmingly positive, with many of the positive respondents being students who have taken Physics II in both traditional and Studio formats. More detailed qualitative and quantitative analyses will be reserved for a longer paper.

DISCUSSION AND CONCLUSION

To date, the CSM physics department has been successful in overcoming the many hurdles associated with a course reform as thorough as Studio Physics. This process took place in several stages for both Physics I and Physics II, which we summarize in the following model:

A) Space Acquisition: Perhaps the most difficult step, we were able to acquire Studio space that would have been otherwise unobtainable by piggybacking off of a non-departmental technology and media building.

B) Initial conversion: The necessary time investment was reduced somewhat by piloting much of the traditional curricular material in the new format. Working with a hybrid Studio/lecture model also eased the implementation burden and reduced certain forms of resistance to change

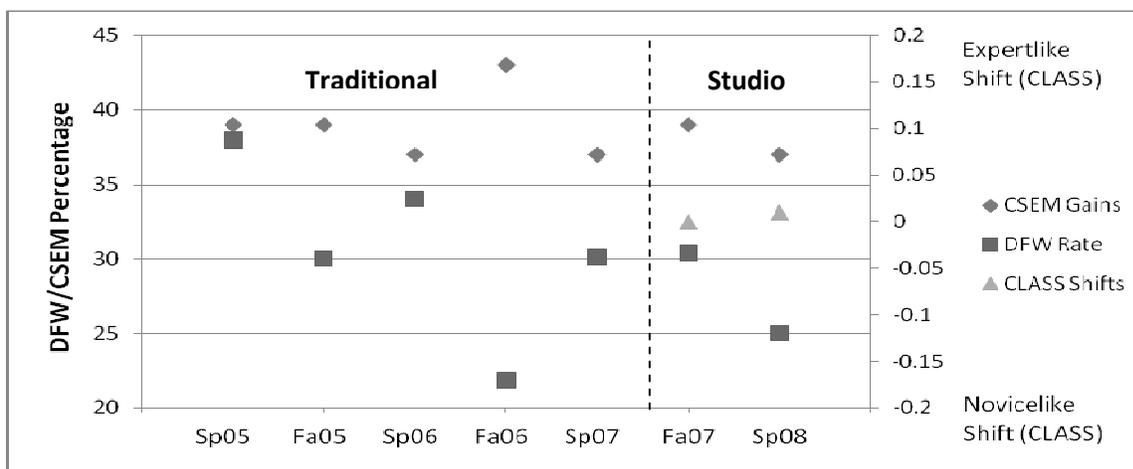


FIGURE 3. CSEM gains and D/Fail/Withdraw (DFW) rates (left axis), and CLASS shifts (right axis) observed in Physics II. The dotted line indicates the transition from a traditional format to a hybrid Studio mode.

C) Iterative improvement: Since implementing Studio Physics II, we have been assessing our course and updating/replacing the curriculum piece by piece as time allows. Drawing on proven curricular advances from PER, rather than reinventing the wheel, has facilitated this process greatly.

Results have been generally positive. Physics I has seen much-improved FCI scores and increased student satisfaction, while tentative results from the not-yet-fully-transformed Physics II are positive or neutral. We expect that as we better match the curriculum to the Studio environment, we will see considerable performance gains in Physics II.

To summarize, departments that wish to use Studio Physics can benefit from getting in on the ground floor with other initiatives, and from implementing the transition in stages. The initial stage can simply be a pilot of the traditional curriculum in the new format. Assessment results from this pilot will inform how to improve the curriculum and pedagogy via research-based innovations. A word of caution: adaptations (as opposed to direct applications) of these innovations are often necessary to match institutional constraints and limitations, but must be made with a clear understanding of the principles behind them. Also, as our results demonstrate, simply transferring a traditional curriculum into a Studio environment or partially implementing reforms will not result in substantial across-the-board impact. Complete reforms over significant time are probably necessary to generate the desired outcomes.

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