The Rensselaer Studio Model for Learning and Teaching: What Have We Learned?

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I. What is a "Studio" model of learning and teaching?

The Studio-based model for learning and teaching in STEM courses is the application of a constructivist-based pedagogy within classroom spaces and schedules specifically designed to facilitate students' ability to interact with others and engage in meaningful activities during their time in class. This model has most commonly been employed at the post-secondary level because in its purest form it requires both a significant deviation from the typical class schedule as well as specifically designed classroom spaces. Both of these are often out of reach at K-12 institutions.

In a Studio course the lecture and laboratory components of the course are integrated. They take place during the same class period and in the same physical space. Activity-based learning dominates over lecture-based delivery of information and so significant chunks of time are required for each class period. The norm is uniform periods of about 2 hours meeting 2-4 times per week. A single specifically designed classroom serves as an effective venue for brief lectures while facilitating students' ability work collaboratively on hands-on activities.[1]

Students' view of how one learns in general and how one learns STEM based material specifically is shifted in studio style courses. Since activity-based, collaborative learning is the norm, students can no longer be passive participants in class. The idea that one's teacher or textbook is the source of all information must be abandoned. Typically, teachers respond to student questions in class by engaging them in a Socratic dialogue as opposed to providing direct answers. Students need to work effectively in groups and communicate constantly about scientific and technical material.

The shifts in expectations for the roles of teachers and students discussed above are difficult for some students to accept at the start. In my experience, students with the strongest academic records seem to be most prone to initial discomfort with this shift in the learning/teaching process. Perhaps this is because they know that they can succeed in a lecture/textbook dominated model of instruction and do not yet know if they will be successful in this new environment. Perhaps it is because this model requires more effort on their part.

Initial discomfort aside, many studies indicate that all students learn better in active engagement courses, including the top-tier students.[2-10] In addition, most instructors with prior experience in activity-based learning environments manage to make all students comfortable in the studio classroom within the first few weeks of the course.

II. Prologues and Epilogues: Connections between the Rensselaer Studio Model other constructivist oriented environments and practices.

The studio model for learning and teaching was first widely employed within STEM disciplines in introductory physics courses for scientists and engineers. The Rensselaer Studio Model evolved from the *Workshop Physics* program developed by Priscilla Laws and her collaborators at Dickinson College.[11] Moving backward in history, *Workshop Physics* had been significantly influenced by preceding, seminal work done by Lillian McDermott, Arnold Arons and others in the Physics Education Research group at the University of Washington.[5,12]

Like studio instruction, *Workshop Physics* involves constructivist pedagogy employed within a specially designed classroom. However, unlike the Rensselaer Studio Model, *Workshop Physics* also includes a published set of guided inquiry student activities which span most topics included in the standard calculus-based physics course.[13]

University faculty tend to view *Workshop Physics* as being too inefficient in regard to the length of time students spend on a given topic, faculty resources devoted to an introductory course and/or classroom space. So, in 1993, then Rensselaer Physics Professor Jack Wilson (now President of the University of Massachusetts system) and Rensselaer Mathematics Professor Joseph Ecker introduced the first studio courses at Rensselaer: Studio Physics and Studio Calculus.[1] These courses specifically, and the Rensselaer Studio Model in general, significantly improved instructional efficiency as compared to *Workshop Physics* and thus made studio style instruction accessible at many more institutions including large research universities. The studio mode of instruction spread quickly at Rensselaer. Soon at least one studio-style course was taught in the vast majority of science and engineering departments on campus.[14]

Today one can find examples of the use of a studio-based model for instruction in all STEM disciplines and at all levels from high school to graduate school. However, these programs now go by many names. The Rensselaer Studio Model has evolved into several similar models including ***SCALE-UP*** developed at North Carolina State University[15] and the ***TEAL*** model developed at the Massachusetts Institute of Technology.[16,17] Both SCALE-UP and TEAL are studio instruction models in which class size has been increased and/or the developers improved upon the original Rensselaer Studio Model in regard to efficient, effective use of classroom space. SCALE-UP optimized the classroom design and furniture configurations. This project is discussed in a companion paper. The TEAL classrooms at MIT are designed for more than 100 students while the Rensselaer classrooms hold only about 50 students.[16]

Again, it is important to note that, unlike *Workshop Physics*, none of these programs, not the Rensselaer Studio Model nor SCALE-UP nor TEAL have a specific curriculum associated with the instructional approach and environment. This makes systematic assessment of the effectiveness of these models problematic in that the "studio shell" can be filled with curricula of widely varying quality. This is discussed in more detail in section IV-A below.

III. Details: Studio-based STEM courses at Rensselaer.

In this section I will discuss the nature of two noteworthy studio-based courses at Rensselaer. First, I will discuss the Studio Physics course which was the first studio course at Rensselaer and so has now been taught in a studio mode for 15 years. Next, I will discuss the "new studio" model course in biology which merges the studio model with on-line learning techniques. Lastly, I will discuss efficiency issues related to the Studio Physics course because I believe the efficiency of the course is in large part responsible for its longevity. This discussion will include important issues related to the use of technology.

A) Studio Physics at Rensselaer:

All introductory physics classes at Rensselaer have been taught in a studio style since the introduction of the model in 1993. The Studio Physics class size at Rensselaer is typically about 50 students. Since nearly 1000 students take Physics I or Physics II per term, this results in as many as 20 sections of the course. Each section is taught by a professor with the help of one graduate and one undergraduate teaching assistant. The integrated lecture/laboratory class sessions meet twice per week. Each meeting is 110 minutes long. This results in a total of about four hours of instruction per week which must include all time devoted to lecture, laboratory and practice of problem solving. In order to cover the breath of material that is traditionally covered in an introductory physics course, this class time must be used very efficiently.

How is classroom instruction time used? The centerpiece of instruction in all studio courses is collaborative group work. The lecture portion of the course is acknowledged to be subordinate to this active learning experience both in terms of time devoted to the task and expectations for student learning. In the typically Studio Physics class at Rensselaer, the first 30 minutes is devoted to working problems on the board. During this time, an instructor models effective problem solving strategies. The next 10-20 minutes are devoted to a brief lecture, complete with the most important relationships, derivations and/or definitions. For the remainder of class time, which is approximately 65 minutes, students work on the collaborative, hands-on activity.[2,18]

B) Rensselaer's "New Studio" Model: The Bio 1010 course at Rensselaer

The "new studio" model[19] developed by Brad C. Lister et. al. and employed at Rensselaer blends a studio style course like that discussed above with asynchronous, web-based learning activities. An exemplar of this approach is the web-enhanced studio biology course now taught at Rensselaer: BIOL 1010 (Introduction to Biology). This course is taught in a studio style but in addition requires online pre- and post-class activities which take about 60 minutes each to complete. After each class, students also have online access to all class materials including lectures and activities.[6]

The pre-class activities typically start with a short video related to some interesting aspect of the current topic. Next, students engage in several additional on-line activities that may include writing an essay, answering review questions, online experiments, simulations, web-based research, data analysis, reading a short article on classic or recent discoveries, and/or a textbook reading assignment.

Like Studio Physics, BIOL 1010 classes meet twice per week for 110 minutes. In-class sessions focus on activity-based learning and lecturing is de-emphasized. Students work in groups answering questions, interpreting data, discovering concepts and resolving misconceptions. The content of the standard introductory biology course is modified to focus equally on just four topical areas: evolution, genetics, molecular-cell biology, and ecology. There is no longer any direct instruction on development, behavior, or physiology.[6]

In-class learning is monitored and enhanced through web-based *concept queries* that are similar to the "clicker questions" many instructors use in lecture halls to improve student engagement.[7] Like "clicker questions", *concept queries* are multiple-choice questions that are first answered individually by students with their responses submitted to and recorded by a computer-based polling system. Student responses are then compiled and displayed. Next students are encouraged to discuss the question with others in the class in an attempt to resolve misunderstandings. These peer-based discussions are facilitated by the instructor and a culminating whole-class discussion including presentation of the correct answer ensues.[7]

Students must complete a set of on-line post-class activities after each BIOL 1010 class. These are similar to those in the pre-class activity, but are designed to solidify and/or expand on the concepts presented in class.[6]

C) Efficiency Issues

Since approximately 1000 students take introductory physics at Rensselaer each year, the Physics I and Physics II courses are broken into a total of approximately 20 class sections, taught by approximately 10 different professors and 20 different teaching assistants. However, all students enrolled in the course during a given semester follow the same syllabus, do the same homework assignments, and take common exams as a single group, both at finals and during the semester. A standard course package including daily PowerPoint lectures, in-class activities and solutions, homework assignments and solutions, and reading assignments is provided by a course coordinator for use by all instructors. The course coordinator is also responsible for exam development.[18]

The motivation for the "course coordinator" administrative model in the Studio Physics courses at Rensselaer is two-fold. First, it greatly reduces the overall amount of faculty time devoted to teaching Studio Physics by reducing redundancy in class preparation efforts. Second, it provides consistency in the material covered by the various instructors. Weekly meetings of all course instructors provide consistent opportunities for input from all those involved and this results in a sense of ownership for all the faculty, not just the course coordinator.

In addition to the administrative model of the Studio Physics course at the Rensselaer, technology is used in several ways that not only promote learning, but also improve efficiency. Computer based data collection and display tools are now widely used in introductory physics laboratories across the country to make measurements with greatly enhanced speed and precision.[20] Laboratory activities that once took 35 minutes in non-computerized settings using stop watches and meter sticks now take less than one minute of class time. The result is that students can make many measurements in a single class period. These data collection systems are not “black boxes’ but rather they are flexible tools which allow self-directed learning even in highly time constrained environments. In addition, there are indications that the real time display of data is important in helping students learn to connect graphical representations to physical situations. Computer based data acquisition allows students to consider a wider range of situations related to a single phenomenon. Many experts feel that consideration of a range of situations is an important part of learning to generalize and transfer one’s understandings.[21]

Another important use of technology in Studio Physics classrooms is web-based homework submission. There are several different web-based homework systems available.[22] All of them allow the assignment and submission of a wide range of types of problems including numerical problems with randomized values assigned to important variables. This means that students can all be assigned the same problem, but the random number generator ensures that they will get different numerical solutions. Hence, working collaboratively on homework is facilitated but blatant copying is eliminated.All the systems provide immediate feedback to the student regarding the correctness of their answer and allow for repeat submissions in the case of a wrong answer, assuming the teacher request this. Many students indicate that the opportunity for multiple submissions motivates them to continue to work on a problem until they get it right. In addition, most of these systems make it easy for the instructor to write and distribute their own problems. This empowers the instructor to customize the level of difficulty or the focus of homework sets to best meet the needs of a specific student population. Lastly, these systems compile statistics on the student responses and provide real time data to instructors on the progress of individuals and/or the class as a whole. This allows a dynamic, student-centered approach to planning how to use class time and interact with individual students.[23]

IV. What can a studio-based course be shown to accomplish? Conceptual Assessment Outcomes

Nationwide, and for decades, Physics teachers have use multiple choice exams such as the Force Concept Inventory (FCI)[24] and the Force and Motion Conceptual Exam (FMCE)[3] to measure student understanding of topics related to mechanics. The developers of the "new studio" model BIOL 1010 course created a similar conceptual inventory appropriate for that course.[6] The standard practice is to administer the same assessment twice, once at the start of the semester and once at the end. Student achievement in conceptual understanding is then measured by improvement in the score from pre-instruction to post-instruction. This is the approach used by both the Physicists and Biologists at Rensselaer.

In order to take into account that a 10% improvement for a student with a 20% correct pre-test score is not necessarily the same as a 10% improvement for a student with a 90% correct pre-test score, a measure called the "fractional gain" or "normalized gain" was developed. The fractional or normalized gain in student conceptual understanding <g> is defined as follows:

$$<g> = \frac{\%\text{ Correct}_{\text{post-instruction}} - \%\text{ Correct}_{\text{pre-instruction}}}{100 - \%\text{ Correct}_{\text{pre-instruction}}}$$

Fractional (normalized) gains are commonly reported within the physics education community and will be reported here.[4]

A) Conceptual Learning Outcomes in Studio Physics: An important lesson

Assessment results have been used in a on-going effort to evaluate and improve the learning outcomes in Studio Physics. An important example of this is the following experiment performed in the early days of the Studio Physics course at Rensselaer (Spring 1998).[2] The goal of the investigation was to determine if incorporation of physics education research-based student activities into Studio Physics would have a significant effect on conceptual learning gains. We investigated student learning outcomes within the Studio Physics course both with and without the incorporation of two proven techniques, Interactive Lecture Demonstrations (ILD)[25] and Cooperative Group Problem Solving (CGPS)[26]. ILD are strongly tied to constructivist approaches while CGPS is based on structured cooperative learning groups and the ideas of cognitive apprenticeship as applied within the domain of quantitative problem solving.[2]

In this investigation, we divided the spring 1998 Studio Physics I sections into two broad categories – "Standard Studio" and "Studio Plus". Both the "plus" and "standard" sections were taught in a Studio mode of instruction. Both groups used the same classrooms, did the same homework assignments, followed the same schedule, had the same lectures and took the same exams. The only difference between these two groups was that the standard classes did not incorporate ILDs or CGPS.

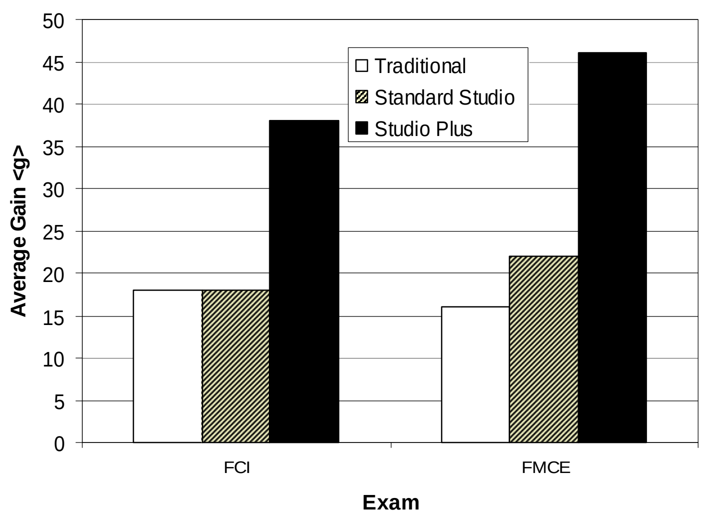

Figure 1: Fractional gain in understanding on two conceptual diagnostic exams, the FCI and FMCE. Standard Studio sections did not include the use of research based curricular materials. The Studio Plus sections did.

Figure 1 gives an overall comparison between the standard Studio, Studio plus and data collected for traditionally structured courses nationwide.[18] The fractional gain represented by the height of each bar is the <g> factor discussed above.

The results of this study suggest that the Studio *format alone* is not enough to improve learning outcomes related to fundamental concepts of Newtonian physics. This is clearly a very important result for those whose main concern is improving conceptual learning outcomes. It indicates that the reasonably small class size (50 students), increased emphasis on hands-on learning and incorporation of technology into the classroom alone can have no significant effect on conceptual learning scores. The curriculum employed within the shell of the studio-model appear to be critically important.

However, it must be noted that class time in the Studio course is greatly reduced as compared to the traditional structure. Hence, this result does likely indicate that time is used more efficiently in the Studio Physics course than in traditionally structured courses. In other words, the studio model of instruction seems to provide an instructional and physical environment where approaches and materials that have been shown to be effective in improving student learning outcomes can be implemented in a highly efficient manner.

B) Conceptual Learning Outcomes in BIOL 1010

Efforts have also been made to measure and compare conceptual learning gains in the traditionally structured BIOL 1010 course and the "new studio" (web-enhanced) version of the course. Specifically, the traditionally structured course as taught in the Fall of 2003 was compared with the interactive course in Fall 2004 using concept inventories for both evolution and ecology. Both classes were taught by the same instructor. He had been teaching BIOL 1010 for almost 20 years. Each course had a similar student composition and pre-instruction measurements indicated a comparable background biology knowledge. In comparing these two courses, a significant increase in learning gain was seen for the web-enhanced, interactive version of the course in evolution (traditional, 0.10; interactive, 0.19; $p = 0.024$) and ecology (traditional, –0.05; interactive, 0.14; $p = 0.000009$). As is the case for the physics assessments, the tests were given without announcement during the last week of classes. These results strengthen the case for augmenting or replacing instructor-centered teaching with interactive, student-centered teaching.[6]

V. Concluding Thoughts and Looking Forward

The deviation from the standard course schedule and access to a specifically designed classroom are two significant impediments to adoption of a pure studio (or SCALE-UP) model of instruction. In addition, many of the fundamental course attributes of a studio model course including: a tight connection between lecture and laboratory materials, an emphasis on collaborative, activity-based learning and an assessment informed focus on improving learning outcomes can largely be accomplished in compromise hybrid models where laboratory periods are converted into "studio" periods and lecture sessions are kept in place. This leads to a series of important, but unanswered questions. How critical is the studio (or SCALE-UP) classroom environment to improved learning outcomes? What can an unadulterated studio approach be proven to accomplish or provide that hybrid (i.e. compromise) models can not?

The efficiency of the Studio Physics course at Rensselaer has been important to keeping the studio-model of instruction in place. Technology plays a significant role in regard to the efficiency of these courses. Web-based homework systems and computer based data collection have empowered instructors and students in ways which make the courses both more effective and more efficient.

However, perhaps the most important lesson learned from Rensselaer's extensive experience with studio model instruction is that the specific curriculum employed in the course is critically important. Simply transforming a course into a studio format will not ensure improved learning outcomes.

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