The New Studio format for instruction of introductory physics

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We have developed the New Studio format of instruction for improved conceptual learning while retaining problem-solving skill development in large, first-year physics courses. This format retains the large lecture, but combines traditional recitation and laboratory instruction. The New Studio format integrates simplified laboratories with assigned homework problems to integrate conceptual and problem-solving skills. The studio format combines 2 hours of lecture with 4 hours of studio each week. The studio is taught for 2 hours twice per week, and consists of up to 40 students working in groups of four at tables equipped with modern instructional technology and apparatus. The group setting allows for peer instruction and development of group skills. The combination of traditional lecture with the studio format enables a research-oriented physics department with a large service teaching load to implement research-based pedagogy. Student gains on the Force Concept Inventory were similar to other courses taught by interactive engagement methods.

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I. INTRODUCTION AND BACKGROUND

Kansas State University is a typical, large, land grant research university, which must do an effective job of educating a large number of students. The 24 faculty in the physics department split their time about equally between teaching and supported research. Approximately 500 students per semester enroll in the Engineering Physics I (EPI) and II sequence, a two-semester, sophomore-level, calculus-based, introductory physics course. In the past the course has been taught in the traditional lecture/recitation/laboratory format. The lecture serves approximately 150 students in each of three sections (two on semester, that is, EPI in the Fall semester and EPII in the Spring, and one off semester), and met for 1 hour twice a week and was taught by a faculty member. The lecture class was divided into recitation groups of approximately 40 students, which met for 1 hour twice a week, and laboratory groups of approximately 30 students, which met once a week for 2 hours. The recitations were primarily taught by faculty members and the laboratories by graduate students or upper-level undergraduates.

In the Fall semester of 1994 the department at Kansas State examined student evaluations of this course sequence. The results of these evaluations showed that students were dissatisfied with the course format. They gave low ratings to the compatibility of the laboratory with the lecture. Written comments often complained that the laboratories were tedious, only vaguely related to the lecture and recitation, and required them to follow the directions in the cookbook-style laboratory manual to obtain preordained results with no need for creative thought. However, students did prefer the smaller class sizes of the laboratory and recitation and the increased student-instructor interaction. In addition to surveys, qualitative data from individual interviews with students, faculty, and laboratory instructors indicated that students had difficulty making conceptual connections between the homework and laboratory experiments. Because these results were in accord with those at similar institutions nationwide, the Department decided that it would be advantageous to change from the traditional lecture/laboratory/recitation format to an interactive, hands-on approach.[1]

Major constraints existed for this change. Any instructional change could not significantly increase the teaching load of our research-oriented faculty. Because space in our physics building is limited, it could not require a significant increase in the classroom space necessary to instruct nearly 500 students per semester. Furthermore, all the faculty must find the changes acceptable because any of them could be asked to teach the course.

II. DEVELOPMENT OF THE NEW STUDIO FORMAT

To devise a new instructional format, the *ad hoc* committee charged with proposing explicit changes discussed recent reforms of calculus-based physics[2,3] and agreed that our current format was effective at teaching problem-solving skills. The committee very much liked the idea of studio instruction,[4] but was frustrated by the fact that the studio method would significantly increase the faculty teaching load and would likely require classroom space beyond the physics building's capabilities.

One of us (Sorensen) was a member of the committee and, in the flux of ideas within the committee, conceived the New Studio format. This format is so named because it uses the studio approach developed at Rensselaer Polytechnic Institute[4] where large lectures have been eliminated and replaced with studios. Our New Studio concept retains the large lectures for 1 hour twice per week. The new aspect of the course design replaces the weekly 2 hours of recitation and 2-hour period of lab by two, 2 hour studios. This lab-recitation combination is the essential feature of the New Studio. By placing these two elements together in the same 2-hour period, problem-solving methods and conceptual

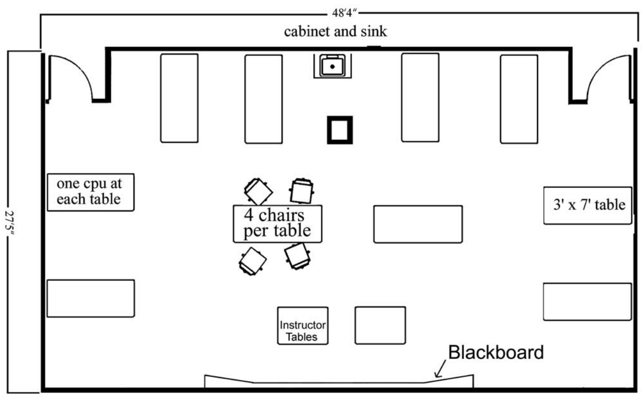

Fig. 1. Diagram of the new studio room.

skills, engendered by hands-on, discovery-oriented laboratory activities, might be successfully integrated. Another important aspect of the plan was to modify the laboratory part by replacing the cookbook-style of our previous lab books with short, concept-oriented laboratory activities. We call these activities "lab demos."

To put this plan into action Sorensen and Maleki were awarded an NSF DUE grant, which, with matching money from the University, provided necessary funds. In the Fall 1999 semester a team consisting of one faculty member (Sorensen), a graduate student (Churukian), and four undergraduates was formed. Sorensen created ideas for lab demos based on 6 years of lecture notes for this course, which in turn were based on the text by Halliday, Resnick, and Walker[5] and previously used lecture demonstrations. The student members of the team took these ideas and built the lab demo prototypes. The team then tested and refined them. The undergraduates had all been students in Engineering Physics in the previous year or two and their insights based on their experience added greatly to the lab demo development. Final versions of the equipment were made in quantity, 11 of each, by our machine shop. Sorensen then wrote the manual of lab demo activities.

In Fall 1999 renovation began on the studio rooms (see Fig. 1). Each room contains ten tables for groups of up to four students. The chairs have wheels to enhance the mobility of the students around the table. Each table is equipped with a computer that sits at one end of the table. The computer contains lab software and is connected to the Internet. One printer in the room is shared by all groups. Near each table are shelves for daily lab demo equipment storage and a place for the students to put their books and backpacks. Also near each table is a small blackboard for "chalk talks" among students or between students and instructors. At the front center are two mobile lecture tables, an overhead projector, and a large blackboard for the instructor. Note that we put the "front" of the room on a long side of the room. These rooms were used previously for labs and then the front was along a short side. This configuration left students at the back very far from the instructor. The new configuration keeps all the students near the front. The ceiling has a grid of beams capable of supporting heavy apparatus.

In the Spring 2000 semester the New Studio format was used for the first time for Engineering Physics I, the off-semester, with about 150 students. In the Fall 2000 semester the New Studio was complete and was used for both semesters.

Table I. Weekly instructional sequence for the New Studio.

Monday	Tuesday	Wednesday	Thursday	Friday
Lecture	Studios all day	Morning studios	Studios all day	Morning studios
Instructors meeting		Lecture		Exams at 3–4 week intervals

III. THE NEW STUDIO FORMAT

The instructional sequence of our New Studio format is outlined in Table I. The Monday and Wednesday lectures are the canonical lecture (which may have as many as 170 students) where concepts and methods are first introduced. The lecturer connects, either by allusion or by direct discussion and/or demonstration, to the lab demos and associated problems that are relevant to the lecture and, hence, will be done in the next day's studio.

As an example, Monday's lecture might be concerned with rolling motion. The lecturer will describe key concepts of rolling motion such as the rolling constraint connecting rotation and translation. Then the lecturer uses these concepts to obtain general results such as the independence of descent time down an inclined plane on mass and radius of the object. The lecturer demonstrates this motion and works an example problem.

In the night between the day's lecture and their studio period the following day the students are expected to study the lecture material and the relevant part of the text, work approximately eight homework problems and conceptual questions, and read the relevant lab demo descriptions. To encourage this behavior random selections of the homework are collected or short quizzes related to the homework are given at the beginning of the studio period and graded.

The class breaks into groups of no more than 40 students who meet in the studio rooms for 2 hours. The studio portion of the course is taught by either a faculty member, post-doc, or senior graduate student, and a teaching assistant team. The students sit in groups of three or four at laboratory tables with the lab demo activity setups. Typically two lab demos and their associated problems are performed per session. There are periods of lab activity during which the professor and the TA walk around the room to aid, interact with, and teach the students, interwoven with the professor (usually) working at the main blackboard to explain a concept or demonstrate the solution to a problem. This variety allows for no dull moments and enhances the rapport between students and instructor.

To continue the example, some of the assigned problems and one of the lab demos for that day concern rolling motion. The students had the night before to try to solve a few rolling motion problems. In studio they can ask for help from the instructors or their fellow students on problems with which they have had difficulty. The instructor works these problems at the blackboard for the whole studio class. Also in the studio the students perform a lab demo to observe and quantify a rolling motion. The instructions for the rolling motion lab demo in our studio manual are given in Fig. 2.

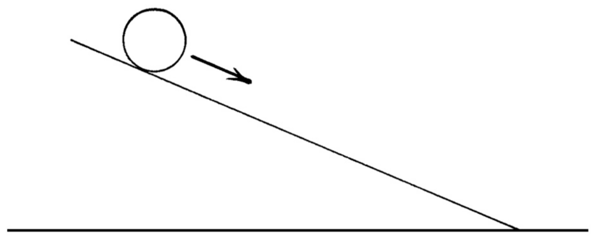

Fig. 2. Rolling motion lab demo. Race different sized and shaped objects down an inclined plane. Use disks, hoops and spheres. Experimentally determine the functionality of time to travel a given distance from rest on mass, radius, and shape. Quantitatively calculate the time for a rolling object to travel from rest down an inclined plane and compare to the measured time.

As can be seen from this lab demo, the students roll different objects down an inclined plane and demonstrate mass and size independence (to within experimental uncertainty). They measure times and speeds and compare to theoretical calculations. This close juxtaposition of analytical problem solving and laboratory experiment is a key aspect of the New Studio, which integrates problem solving and hands-on experimentation.

IV. FUNDAMENTAL ASPECTS OF THE NEW STUDIO FORMAT

The lab demos are constructed to be tangible examples of physics concepts or important homework problems in an effort to build conceptual skills. Many of the lab demo activities, which take between 5 and 30 minutes, were inspired by popular lecture demonstrations. Hence they represent a way to allow the students to do the demonstrations themselves. Some of the activities are very quick, "aha!" type visualizations of the concepts. Others are more involved and require data collection and analysis. All are described in the student's manual with brevity. This manual describes what the student should do, but does not lead the student step-by-step. Thus some thought and self-reliance are required of the student.

Problem solving skills are not neglected in favor of concept building. Rather they are fostered by retaining recitation style problem solving instruction as part of the New Studio. The New Studio format does more by integrating the assigned problems with the lab demos. In the example given in Fig. 2 the students solve problems on rolling motion down an inclined plane and find algebraically the independence of the decent time with mass and radius. Then they roll real objects down an inclined plane and discover this same lack of dependency. This integration, which is a key component of the New Studio, makes the problems become more meaningful with real world manifestations. It also anchors the lab demo experimentation to the fundamental principles and their mathematical embodiment.

- Spin the crank of the hand generator with no electrical connection (that is, no load). Note the torque you must apply.
- Now connect the generator to various loads of about 100 ohms, 10 ohms, and short-circuited (R_{load} ~ wires' resistance). Qualitatively note the torque you must apply. For what value of load is the torque the greatest and the least?
- Is a large load a big resistance or a small resistance? Explain why the crank is harder to turn when the load is there. To do this use conservation of energy, conversion of mechanical to electric energy, and rotational work being torque times angle turned.
- Connect the hand generator to the oscilloscope function of the lab computer. This will give you an instantaneous picture of the output voltage as a function of time. Crank it at different rates and explain what you see.

Fig. 3. Electrical generators lab demo.

Laboratory skills are also developed. Students learn mechanical skills, learn to measure, and encounter experimental uncertainty. Integration with the problems allows them to compare theoretical expectations to experimental results. This comparison teaches them how to compare theory to experiment with experimental uncertainty. A well-kept lab book is graded, but we purposely do not collect formal lab reports. We believe these distract the student from what we prefer to emphasize: discovery, hands-on interaction with phenomena, as well as systematic observation and comparison to hypothesis, in other words the scientific method.

We have found that during lab demo times in the studio considerable activity and discourse occur at each group table. It appears that, as the students work in groups, considerable peer instruction occurs. These groups are permuted a few times per semester to alter and keep fresh the group dynamics.

Course content is retained; no subject material was removed. In a 30-week academic year we cover mechanics, thermodynamics, electric and magnetic fields, DC and AC circuits, and geometric and physical optics, and touch on modern physics with some weighting dependent on the lecturer.

The large lectures remain due to the large number of students we instruct, the lack of room space needed if we were to lecture to small groups, and our desire not to significantly increase our teaching load. Much has recently been said and written about how little students retain during a lecture.[6] However, the lecture can guide and, when done well, inspire. It offers a model of expert problem solving and articulation of concepts. It can consolidate and give the big picture.[7] Moreover, by incorporating a variety of different teaching methods, we provide opportunities for students with many different learning styles. Students who can learn by listening have an opportunity to do so as do those who learn best with hands-on activities. Most importantly, each teaching-learning method is integrated with all of the others. The lecturer connects his/her presentations to the homework and lab demos. The lab demos are constructed to provide conceptual reinforcement to the mathematics of the homework. And all studio activities connect to the concepts presented in lecture. Thus, the many different approaches provide multiple learning methods for each major concept.

V. THE LAB DEMOS

We have created 129 lab demos covering the entire subject matter range. (Copies of the Studio Manuals with all 129 lab demos can be obtained from Sorensen.) In the academic year there are 60 studios, which averages about two lab demos per 2-hour studio. The average lab demo takes half an hour so that there are 50 minutes for recitation-style problem solving. We believe it is important to keep this balance between the lab demos and problem solving.

Many of the lab demos require quantitative measurement and comparison to theory. The rolling motion lab demo in Fig. 2 is an example. These are important because they connect and compare measured numbers to calculated numbers.

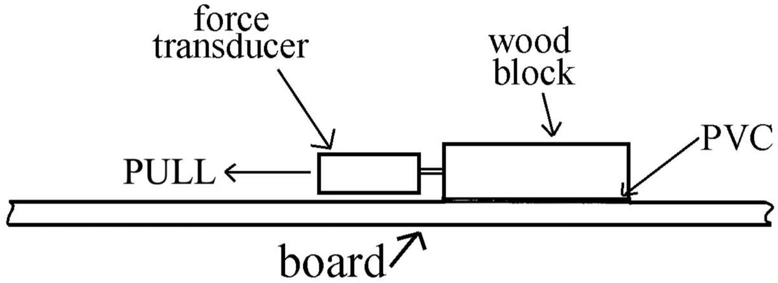

Fig. 4. Static and kinetic friction—On the level lab demo. Set up the computer system with the force transducer so that force can be measured as a function of time. Place the block of wood with PVC on one side on the inclined plane board, PVC side down, level on the table. Push the mass with the force transducer by hand, starting with little effort but continuously increasing your effort over a few seconds until the mass slips and then for another second or two with the mass slipping. Examine the recorded trace of the force as a function of time and make sense of it relative to the concepts of static and kinetic friction. Calculate the friction coefficients μ_s and μ_k. Redo with more mass stacked on the original mass and find how friction depends on the normal force. Would a horizontal pull yield different results from the push?

Experiments that use simple measuring devices are very useful to keep the physics at its most fundamental and intuitive level. For example, consider the lab demo in Fig. 3 concerning electrical power.

This lab demo puts conservation of energy at the student's finger tips. The students develop a sense for how resistance is related to load and also see a real time graph of the generator output due to electrical induction.

The computer is used for measurement when its powers can help the student develop visual concepts. For example, consider the friction lab demo in Fig. 4.

In this demo a force probe interfaced to a computer shows the force applied to a block at rest on a table as a function of time as the student slowly increases the force by hand. Eventually, the static frictional force maximum is exceeded, the block begins to slide, and the frictional force falls to a smaller kinetic value. With a little practice, the student can produce a graphical display on the computer of the increasing static resistance and the precipitous fall to the nearly constant kinetic value once sliding begins. Students gain a feel for friction through their finger tips and connect a graph to their experience with the help of the computer.

Whole studio class experiments are used when it would be impractical to have ten replicas of the lab demo either due to economy or lack of space in the studio room. For example, the center of mass lab demo in Fig. 5 is used to demonstrate internal forces.

Two students, preferably of unequal mass, sit on carts facing and touching each other. Then one or both push against the other with their feet. Other students at their backs use sonic rangers to record their velocities while other students monitor the computer traces of these velocities as a function of time. Because the carts come to rest in the second part of the demo, there are external forces and, hence, the center of mass might move. This motion is discovered empirically, usually as a bit of a surprise, which often leads to vigorous discussion by the group. These total group lab demos are the least numerous, but appear effective in teaching physics and in developing team skills and a sense of community.

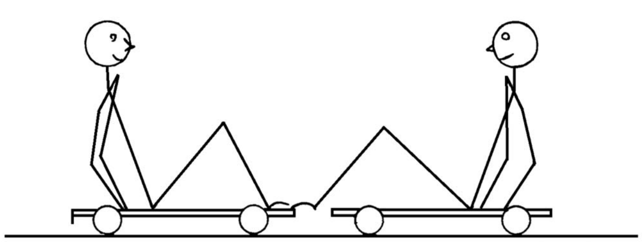

Fig. 5. Center of mass and internal forces lab demo. **Lab Demo** Have two people sit on two roller carts facing each other. Set up sonic rangers behind them to measure their velocities. Measure the mass of each person plus cart. Have one or both people (does it matter?) push away from the other. Measure and compare their velocities immediately after the push. Explain your measurements. Measure the position of the center of mass before the push and after carts come to rest.

The "quickies" are numerous and perhaps the most fun. They take approximately five minutes, but they set a concept through a memorable experience. Students jump from tables while holding paper cups filled with water leaking from a hole to demonstrate zero gravity; they crow-bar large, highly charged capacitors and see an energetic spark; they squeeze a laser beam between their fingers and demonstrate diffraction; they drop a basketball and a tennis ball together, one over the other, tennis ball on top, and demonstrate a wild yet very informative collision process (imagine ten groups doing this at the same time in the studio room); or they sit on rotating stools, spinning with weights or heavy, gyroscopic spinning wheels in their hands.

VI. ASSESSMENT OF OUR CHANGE TO THE NEW STUDIO

We administered the Force Concept Inventory (FCI) to all Engineering Physics I students during the first three semesters that we taught the course with the New Studio format. The FCI was also administered to students enrolled in the old recitation-lab format in the year previous to the change (Spring 1999).

To test conceptual gains during Engineering Physics II one of us (Churukian) created the Survey of Electricity, Magnetism, (DC) Circuits, and Optics (SEMCO) in August 2000. SEMCO is a survey designed to assess student conceptual understanding of electricity, magnetism, DC circuits, and optics. Rather than creating new questions, the questions on the survey were selected, with the permission of the original authors, from five separate, preexisting conceptual surveys for these topics. The selected questions were then evaluated by two independent faculty members of the Kansas State Physics Department and deemed to be representative of the most important concepts the students should understand upon completion of the course. All questions were taken

Table II. Comparison of pre- and postinstruction summary for the Force Concept Inventory.

Course	Fractional gain	Fractional gain standard deviation	Fractional gain standard deviation of the mean	Effect size	Lecture instructor
Traditional Spring 1999	0.17	0.30	0.030	0.46	A
New Studio Spring 2000	0.42	0.31	0.028	1.53	B
New Studio Fall 2000	0.41	0.25	0.016	1.71	C
New Studio Spring 2001	0.39	0.26	0.028	1.59	B

from inventories that have well-established reliability and validity. This survey was created too late to test the pre-New-Studio sections but was administered to two sections of the New Studio.

Tables II and III display pre- and postinstruction results and relative gains for the FCI and SEMCO, respectively. We used two quantitative measures to compare the prestudio and studio classes. Fractional gain (sometimes called the Hake gain) normalizes scores to the maximum possible gain, while effect size normalizes to the standard deviation:

$$\text{fractional gain} = \frac{\text{post}\,\% - \text{pre}\,\%}{100\,\% - \text{pre}\,\%}, \tag{1}$$

$$\text{effect size} = \frac{\langle \text{post} \rangle - \langle \text{pre} \rangle}{\sigma}, \tag{2}$$

where σ is the standard deviation of the difference between the pre- and posttest scores.

Table II shows the fractional gains on the FCI, which were nearly 2 1/2 times better using the New Studio method compared to our traditional method of instruction. The fractional gains of about 0.4 on the FCI that our New Studio method yielded compare well to other, innovative instructional methods recently reported.[1] Table III shows similarly good gains for the second semester on our SEMCO survey. In both semesters similar gains were achieved for each lecture instructor (designated as A, B, and C for anonymity).

In another comparison of pre- and postimplementation of the New Studio format we used four of six problems from an exam given in 1989 by Sorensen as 2/3 of an exam given in Spring 2000 under the New Studio format. In both 1989 and 2000 the exams were graded by teaching assistants who were provided a key by the instructor. The graders were given the same instructions regarding procedures. The graders of the exams in 2000 were not told that the course was a new approach. Thus, we minimized any Hawthorn effect. The class average on the 1989 exam was 50% while the average on both the exam and the four problems was 65% in 2000. Although not a direct comparison, this improvement suggests that the students were doing better.

Churukian, under the guidance of Zollman, conducted extensive interviews of both students and instructors. In general, both groups were very positive about their experience with the New Studio. The students liked the hands-on nature of the course, the integration of homework problems with the lab demos, and the strong interaction with both the instructors and their peers. Negative responses were rare and involved details. Most indicated they would change nothing about the New Studio. The overall reaction of the instructors was also very positive. More details about these evaluations and an extensive series of interviews of both the students and the instructors will be presented in a separate publication.

Cohen[8] defines a large effect size as any value over 0.8, while those between 0.5 and 0.8 are considered medium. The results displayed in Tables II and III indicate that the effect size of the gains in the New Studio are large by Cohen's criteria.

The fractional gains on the FCI for the New Studio are consistent with Hake's data for classes that are taught by interactive engagement methods. Our gains for the traditional class are also in the range for traditional classes stated in Ref. 1.

VII. CONCLUSIONS

Our results are for a course that significantly increased student interactivity. The new format did not require additional classroom space or teacher contact hours. Maintaining the lecture component has not had a negative effect on gains and may have helped students who have diverse learning styles. The gains are on par with those obtained through

Table III. Comparison of pre- and postinstruction for the Survey of Electricity, Magnetism, (DC) Circuits, and Optics.

Course	Fractional gain	Fractional gain standard deviation	Fractional gain standard deviation of the mean	Effect size	Lecture instructor
New Studio Fall 2000	0.42	0.21	0.020	2.00	B
New Studio Spring 2001	0.29	0.19	0.015	1.47	C

other styles of interactive instruction. Moreover, there has been no removal of subject matter nor deemphasis in problem solving skills. We could say that the New Studio is a hybrid that includes the best of the traditional lecture/recitation/laboratory format with new physics education research concepts of interactive, hands-on explorations and peer instruction.

ACKNOWLEDGMENTS

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Differential Pulley. The apparatus can be used in various ways. For example, strings can be wound in different directions around the two sections of the axle, and masses hung on their ends to give rotational equilibrium. This is a demonstration of the differential pulley used today as a lifting device in automotive and machine shops. The two ends of a chain are wound in different directions around the two parts of the axle, and a pulley is suspended from the middle of the chair. A small pull over a large distance on the chain causes the pulley to rise slowly and lift a large weight. The device is in the Greenslade Collection and was made by Max Kohl of Chemnitz, Germany ca. 1900. (Photograph and Notes by Thomas B. Greenslade, Jr., Kenyon College)