THE SCIENCE STUDIO—A WORKSHOP APPROACH TO INTRODUCTORY PHYSICAL SCIENCE

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Abstract

This paper describes the Science Studio, an innovative workshop approach for instruction in a physical science course that combines aspects of traditional lecture and laboratory. The target audience for this introductory course is non-science majors, including prospective teachers. An inquiry-based, technology-rich learning environment has been created to allow students hands-on, in-depth exploration of topics in physics, and earth and space science. Course philosophy, course development, and sample activities are described in this paper, along with outcomes from a project-wide evaluation of the Virginia Collaborative for Excellence in the Preparation of Teachers (VCEPT), an investigation of change in student attitudes and the lasting impact of the studio model at Norfolk State University.

Introduction

There has been an extensive body of work over the past twenty years documenting the shortcomings of traditional modes of instruction at improving the learning of physics at the introductory level [1]. The concept of the Science Studio arose from a decade-long movement within the physics education community to create a rich, alternative learning environment for students that mirrored more closely the process of scientific exploration as practiced by experts. Leaders in this field were Jack Wilson at Renssalear Polytechnic Institute (Studio Physics) [2] and Priscilla Laws at Dickinson College (Workshop Physics) [3]. The defining characteristics of workshop/studio physics classes are an integrated lecture/laboratory format, a reduced amount of time devoted to lecturing, a technology enhanced learning environment, collaborative group work, and a high level of faculty-student interaction. The learning environment employs inquiry activities, computer tools, and multimedia materials that allow students to actively participate in their own learning. A high priority is placed on allowing students to learn directly from their interactions with the physical world through "hands-on" activities. However, the Renssalear Polytechnic Institute (RPI) and Dickinson courses were designed for the calculus-based introductory physics course and there was a clear need for the approach to be applied to the non-science majors physics or physical science course. The Dickinson College group started work on

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the Workshop Physical Science curriculum, now being published by John Wiley and Sons as *Explorations in Physics* (2002), at around the same time that the Science Studio concept was being formulated at Norfolk State University (NSU) in the mid-1990s.

Motivation

The Science Studio was initially offered as a pilot section of *Physical Science 100*, a course in the Department of Physics, which helps satisfy the University's general education science requirement. Most students who enroll in *PHY 100* are non-science majors, with about 30% intending to seek teacher certification. The course was structured as a 3-credit hour lecture with an optional separate 1-credit hour laboratory course. As a service course, it remains very important to the department, but little assessment data existed to indicate whether the course was effective in enhancing student comprehension of the process of science or whether student attitudes toward science were positively impacted by enrollment in either lecture or laboratory sections. In addition, due to the separated credit, there was no coordination between topics covered in lecture and those covered in the laboratory course and more importantly, students were often not enrolling in the lecture and laboratory sections in the same semester. The recent literature on the teaching and learning of physical science points toward active engagement strategies and guided-inquiry techniques as having the most success in fostering student learning of difficult, abstract concepts embodied in the physical sciences [4,5]. If students take the lecture and laboratory sections in different semesters, it is of course very hard for them to make connections between theoretical and applied portions of the course. The Science Studio was designed to address this barrier to student learning by eliminating the separation of lecture and laboratory.

Another motivating factor for this author was a desire to continue research on student learning using advanced technologies (such as Microcomputer Based Labs [MBL] and Video Based Labs [VBL]), on which some studies had been published in the literature, but none had been completed at a minority institution [5,6,7]. The emergence of instruments such as the Views About Science Survey from Arizona State University [8] afforded the opportunity to evaluate the course not only on the cognitive level, but also in the affective domain.

Goals

The goals of the Science Studio project are in line with the Virginia Collaborative for Excellence in the Preparation of Teachers (VCEPT) criteria for course development. It is expected that successful Studio participants would have:

- increased their scientific literacy and improved their critical thinking abilities;
- acquired mastery of a diverse subset of physical science concepts;
- improved their skill and confidence level using communication technologies, including computers and multimedia;
- increased their ability to read graphs and interpret their meaning;
- developed more positive attitudes toward science.

In addition to these general education goals appropriate for all students, the course was designed to enable pre-service teacher candidates a chance to acquire skills and knowledge they could pass on to their own students in the K-12 classroom. This goal is becoming increasingly important in view of national and state accreditation agency policies that require teacher preparation colleges to demonstrate that their graduates are contributing to student achievement in the K-12 classroom.

Scheduling

Two separate sections of the Studio have typically been offered—one for students in the University's Parsons Academic Honors program and another that is open to all students. On occasion, due to low enrollment, students in the Honors section have been combined with the "regular" section. There was no difference in the instructional approach taken with these two groups of students. While the Honors students were observed to be more motivated to complete assignments and clearly possessed higher-order communication skills, their class attendance was not manifestly different from other students enrolled in the Studio (average 70-75% attendance). To facilitate the Studio model without creating a new course, students were required to sign up for *both* the 3-credit hour (CH) lecture course (*PHY 100*) and the 1-credit CH laboratory course (*PHY 100L*) which was scheduled to immediately follow the lecture section. These courses were listed separately in the course schedule booklet, and both were shown to be taught by the author of this paper.

The Studio was scheduled to meet for two and one-half hours each on Tuesdays and Thursdays to give a total contact time of five hours, equal to the three hours of lecture plus two hours of laboratory in a traditional model. However, the University's registration system did not permit the department to ensure that the *same* group of students was enrolled in both the "lecture" section and the "laboratory" section of the Studio. This lack of coordination resulted in mass confusion during the first few class periods, as students sorted out the unusual constraint of being required to have the same instructor for both lecture and laboratory and being required to enroll in the lecture and laboratory in the same semester! With departmental cooperation, the Studio was scheduled to meet in a laboratory room almost exclusively reserved for this purpose. This allowed student experimental setups to remain assembled in between class meetings and greatly facilitated course logistics.

The Studio Environment

Average enrollment in the Science Studio was 12-18 per semester over a four-year period with one instructor. On a few occasions, a student assistant has worked with the author. In each case, the assistant was a graduate of the course, interested in teaching, comfortable with technology, and able to lead group discussions. Six "stations" were available—each comprised of a relatively fast computer, data acquisition equipment (see below) and appropriate software packages. On occasion, students have had to work in groups as large as four, but the typical size has been two or three. Students are encouraged to form groups right away, but due to the fluid nature of enrollment in an introductory non-majors' course (and the scheduling issues with the Studio described above), group size and composition rarely stabilized until after the fourth class period.

From this author's experience, a class size greater than 24 would be unmanageable for one instructor. For any group larger than ten, the presence of a laboratory assistant would greatly facilitate student learning, as intensive demands are put on instructors in a Studio session. The Studio is inherently constructivist in nature and it is important to guide students' thinking rather than giving them the answer via a lecture (the latter being more efficient for the teacher). Students with prior experience in physical science often use words such as "force," "velocity," and "acceleration" to answer questions on mechanics concepts with only a superficial understanding of how to apply them. The hands-on nature of Studio activities (described below) requires students to connect these terms with real-world data they are collecting and requires instructors to constantly engage in Socratic dialog with students to ensure they successfully do so. The Science Studio has only been taught by one instructor so far at NSU (the author) because special training/exposure is necessary to develop the attitude and skills this instructional model demands. Further details on instructor preparation are provided later on in this article.

Data Acquisition

From the various commercial options available for real time data acquisition equipment, the Personal Science Laboratory (PSL) from TeamLabs was chosen for the Studio. There were two reasons for this: (1) the PSL equipment is rugged and built to withstand the company's principal users who are in K-12 classrooms; and, (2) they offered the Windows-based *Excelerator* software for acquisition, control, and analysis which is an application add-on for *Microsoft Excel.* Thus, students familiar with *Microsoft Office* environments would not have to learn any additional user interfaces to use the basic features of the probeware software—a significant advantage. A PSL "station" typically comprises a computer (optional Internet connection), an analog-to-digital converter (connected to the computer via serial or USB port), various sensors (ultrasonic distance probe, force probe, temperature probe, etc.) and other supporting laboratory equipment, such as Pasco dynamics carts, air tracks, pulleys, glassware, etc., as needed.

Studio Curriculum

The approach to curriculum design in the Studio was informed by research on student learning in the sciences and by the concurrent development of instructional materials in the Workshop Physical Science project, *Physics By Inquiry* [9], from the University of Washington group and by the American Association of Physics Teachers' (AAPT) *Powerful Ideas in Physical Science* [10]. All these approaches emphasize limiting the number of topics covered in the course to allow students to build robust mental models of a select few natural phenomena. For the NSU Science Studio, the course topic sections were: "Motion and Mechanics," "Solar System," and "Seasons." Students working in small groups completed guided activities in each of these areas. Approximately eight weeks were spent on mechanics and the other half of the semester divided equally between space science and climate change.

An appropriate textbook did not exist for the Science Studio. The author compiled a collection of instructional materials, multimedia resources, and Internet sources that was provided to the students free of charge. Many of these items were purchased with grant funds or obtained through the author's collaborative relationships with curriculum developers and continue to be available for student use in *PHY 100*. In the current era of custom electronic publishing being promoted by many textbook publishers, it should be possible to compile appropriate instructional resources from multiple sources and make it available through the campus bookstore at a cost no greater than that of a traditional textbook for physical science. The materials used in the Studio are provided in the references.

After completing several guided-inquiry activities, students designed their own Motion Experiment as a group project and made a formal presentation to their peers using *PowerPoint*. Approximately 50% of the course grade depended on the student successfully completing classroom activities throughout the semester, 25% was based on group project(s) that typically required several hours outside the classroom, and 25% of the grade was based on quizzes and tests. Since group projects and activities can be adversely affected by the absence of certain members, the grading scheme for many Studio activities had equally weighted portions for group and individual achievements. As mentioned earlier, the attendance has averaged 70-75% over the four years that the Studio course has been offered, often a hindrance to group completion of activities on time.

While working on their group projects, students invariably ran into all kinds of problems they had to solve. These problems ranged from deciding on when the group would meet (no mean feat since many NSU students juggle school, a job, and family) to trying to figure out how to apply their classroom knowledge to a new situation. In short, they were put in a very real-world situation in which they had to work with other people to produce something by a specific deadline. The experiences gained through this aspect of the course were valuable life lessons, even though they did not appear as learning objectives in the course syllabus.

Motion and Mechanics

Exploration of topics in motion utilizing kinesthetic approaches, as made popular by Laws [11], Thornton and Sokoloff [6], and others, played an important part in this section of the course. Special emphasis was placed on learning the mathematics of change from position versus time graphs generated by the probeware system. Non-science majors often have minimal mathematics preparation, yet it is important, especially for the pre-service teachers, to see the connection between real-world phenomena and the mathematical language in which they can be described. A typical set of graphs that have been used on numerous occasions on tests in introductory courses is shown in Figure 1 below, along with a set of questions that requires a working knowledge of slopes, and helps students demonstrate their comprehension of an *operational definition* of the fundamental quantities involved in the study of motion. While no formulae appear, mathematical rigor has not been sacrificed. Learning activities adapted from the Workshop Physical Science and TeamLabs curriculum guides comprise the MBL experience for students in the Science Studio. Desktop digital video has been available as a tool for education

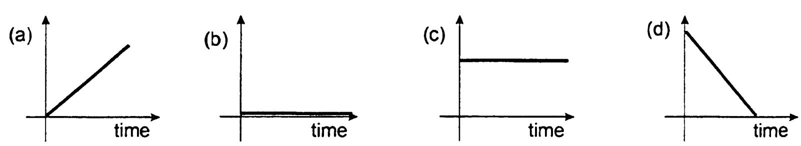

Figure 1

Question 1. The professor walks at a steady pace from one end of the room to the other. If we measure his distance from the starting point, which graph best shows how his POSITION changes as a function of time? (i.e., POSITION is being plotted on the vertical axis).

Question 2. For the motion described above, which graph below shows how his VELOCITY changes as a function of time? (i.e., VELOCITY is being plotted on the vertical axis).

Question 3. For the motion described above, which graph below shows how his ACCELERATION changes as a function of time? (i.e., ACCELERATION is being plotted on the vertical axis).

for over ten years. A variety of low-cost systems now make it extremely affordable to allow students to take their own video footage of an interesting phenomenon in the world and use graphical analysis software to analyze it frame-by-frame [7,12]. In the Science Studio, two computers are outfitted with Intel Smart Video Recorder III cards, which enable the capture of video onto disk from a camcorder. The software tool that has been used in the Studio is *VideoPoint* [13] that allows extensive analysis of video data.

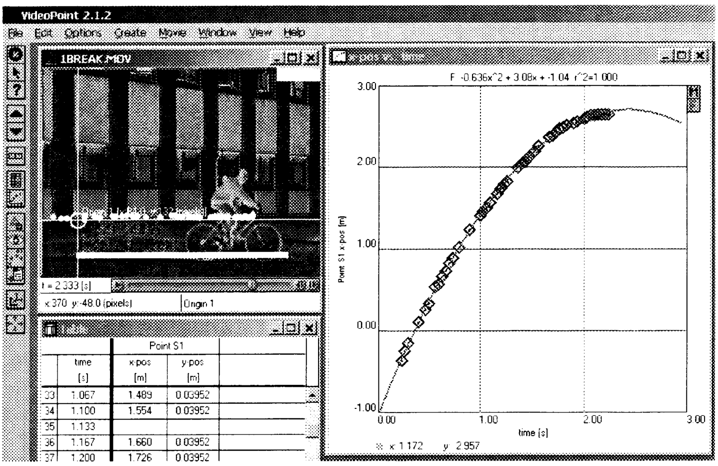

Figure 2

In the screen shot from *VideoPoint* shown in Figure 2, the video window (top left) has been color-inverted to bring out the image contrast. The video shows a student riding a bicycle across a predetermined distance (thick white line in video). On each frame of video, the location of the handlebars (picked for convenience) is marked. These show up as white dots on the Figure. The rider entered the camera view at a constant speed and then applied the brakes, stopping at the last white dot. The thick white line represents a known distance, marked on the ground by soda bottles, which is used to convert screen pixel distances to units of meters (the ruler tool in *VideoPoint* is used for this).

Once the student has marked with a mouse the location of the chosen point in each frame of video, a graph of x-position versus time is constructed. With the origin of the graph chosen to coincide with the start of the predetermined riding distance, a simple curve fitting routine built into *VideoPoint* is applied to determine the best fit. Students then compare this fit to the known kinematic equations of motion and can extract such information as initial velocity, acceleration, total time of travel, etc. Students contrast graphs of uniform motion with non-uniform motion in terms of the slope. They are able to build on and solidify their previous experience with MBL graphs. The decreasing slope in the case shown here would indicate the rider is *slowing down*.

An important feature of this activity, related to student affect, is that they not only collect their own data, they actually *create* their own data by taking a video of one of their group members riding the bicycle. VBL activities have been a very popular choice for group projects. Some subjects chosen for analysis were "basketball three point shots," "trampoline jumps," as well as, "the behavior of mechanical toys."

Solar System

While most college students can recite the names of the nine planets, the size and scale of objects in the solar system pose problems for them. The Science Studio students entered the course with misconceptions that were no different from the vast majority of non-science majors taking an introductory astronomy or physical science course. At NSU, students were asked to submit hand drawn sketches of their concept of the solar system, with as much detail as they were able to provide. This elicitation activity gave the instructor some insight into the initial state of students' mental models and a sense of how large the knowledge gaps were.

To help students build a picture of the solar system that more accurately represented the current state of knowledge, a variety of sources were used. Initially, the Studio was not wired for Internet access, so CD-ROMs produced by NASA [14] and clips from a Physics Cinema Classics videodisc were used to guide student learning. Students built an appreciation of orbits, relative sizes of planets, and a true understanding of the components of the solar system. For instance, students often think that the millions of stars visible in the night sky are actually part of the solar system (a preconception that was illuminated by the elicitation activity and one that largely disappeared as measured by post-instruction assessment). When scheduling permitted it, students took a virtual reality tour of the solar system using advanced Silicon Graphics workstations in the NSU scientific visualization lab.

Reason for the Seasons

The final section of the Studio was based on the question, "Why is it warmer in the summer and colder in the winter?" This question was made famous by the "Private Universe" video [15] that showed Harvard University graduates unable to give a correct scientific explanation of the reason for the seasons. At NSU, an elicitation question opened the discussion of this topic, with results similar to the Harvard experiment [16]. A short excerpt from a student paper follows:

> It is warmer in the summer because of the rotation of the earth and the relativity to the sun. The (distance) between sun and the earth is shorter [the student used units of light years on his diagram to indicate this], meaning an increase in temperature. It is colder in the winter due to rotation as well...and results of winter and summer are attributed by the tilt of the earth as well.

Clearly this student knew terms such as "rotation," "relativity," "light years," and "tilt of the earth," but did not know how to use them to explain the phenomenon of seasons.

Two innovative software tools have been used in the Studio to help students learn about the seasons (and lead into a topical discussion of greenhouse effect and global warming). A simulation program called *Seasons* [17], from Riverside Scientific Software, allowed students to change the distance of the earth from the sun and the tilt of the earth's axis to observe temperature variations at multiple locations on the earth. Students then used a scientific visualization software tool called *WorldWatcher* [18], developed at Northwestern University to create false color maps of global temperature distributions obtained from satellite measurements and compare quantities, such as total amount of energy received in each hemisphere during summer or winter months. Students completed learning activities to gain an appreciation for the role of the earth's axial tilt in seasonal changes—leading to more intense sunlight, longer daylight hours and a net shift in the energy balance between summer and winter. Since the global scale of these phenomena is hard to reproduce in the laboratory, the interactive software tools provided students an environment in which they could interact directly with the relevant physical variables and further refine their observation, analysis, and communication skills.

Course Assessment and Evaluation

Student performance in the Science Studio as measured by grade distribution has not been substantially different from lecture sections taught by the instructor. While attendance is a critical component of student success in the Studio, general education courses not in their major field are often given short shrift by students. Thus, student attendance issues affect all sections of *PHY 100*. While the Studio model definitely succeeds in engaging students, it has not made a significant difference in either student attendance or final grade distribution. The most interesting outcomes of the Studio have been with regard to student attitudes toward science and this is described further in the sections below.

Student Attitudes

In Spring 1997, an attitudinal survey based on the Views About Science Survey (VASS) [8] was given at the beginning of the semester to 200+ *PHY 100* students across multiple course sections. Included in this group were the Studio participants as well as 70+ students enrolled in a "traditional" lecture section taught by the author. The Studio curriculum was very similar to what has been described above, while the lecture course followed the standard textbook and covered a wider variety of topics. Every effort was made to bring interactive, visual demonstrations into the lecture, including NASA images, MBL, and clips from videodiscs. A teaching assistant facilitated course logistics in both the traditional section and the Studio section.

The VASS uses a Contrasting Alternate Design (CAD) and asks respondents to choose a degree (1-7) of agreement between two extremes (a) and (b) of an issue: e.g., "Learning physics requires (a) a serious effort OR (b) a special talent." Students choose (1) if they agree with the (a) statement and (7) if they agree with the (b) statement, or a number in between if some middle ground between the two contrasting statements fits their views. Typically, one of the statements could be associated with scientific expertise while the other with a naïve, folk view of science. The NSU attitudinal survey, modified and simplified to aid the research, was administered to 125 *PHY 100* students at the end of the semester (including the author's lecture section). For validity checking, the Studio students completed the full VASS. The VASS classifies responses as either being expert (the professional scientists' view of the importance and relevance of science), folk (a novice's view of science), or mixed (having features of both expert and folk). At the beginning of the semester, the Studio students had views similar to the rest of the student body surveyed. The results from the post-survey clearly indicated that regardless of instructor, students enrolled in the traditional lecture did not shift their views about the importance or personal relevance of science. On the other hand, the Studio students (who completed the full VASS) *appreciably shifted toward expert views* on a number of VASS dimensions. While it was personally disappointing for the author that the attitude of his lecture section students shifted no more than that of his colleagues, the power of the Studio model to change student attitudes emerged from this study [19].

VCEPT Evaluation

In Fall 1999, the Science Studio participated in the VCEPT project evaluation [20]. Students used a five-point rating scale to describe the *presence* and *value* of course characteristics as shown in Figure 3.

To what degree did the classes in this course include...	To what degree are these course characteristics important in helping you learn in this course...
A = Systematic Use (100% of classes) B = Customary Use (75-99% of classes) C = Frequent Use (50-74% of classes) D = Moderate Use (25-49% of classes) E = Occasional Use (0-24% of classes)	A = Very Important B = Important C = Unimportant D = Detrimental to your learning E = Not Applicable or No Opinion
Figure 3	

While the complete details of the evaluation will not be repeated here due to space limitations, student responses on several individual items are instructive when considered against the goals, objectives (and limitations) of the Science Studio. On the questions that highlight the strengths of the workshop/studio model—"active student learning," "up-to-date teaching technologies," "effective interactions amongst students," "opportunities to collect/organize/analyze information," "opportunities to communicate conclusions and ideas," and "assessment of student performance in different ways"— Science Studio ratings were significantly above the VCEPT-wide ratings. In areas such as "critical thinking about current events" and "ethical and social implications in the world," which were not emphasized at NSU, the Studio was not rated as highly as it was on the first set of criteria. However, the Studio still scored substantially higher than the large group averages on these questions. Finally, the questionnaire had three questions targeted at teacher candidates enrolled in VCEPT courses. In the NSU course, ten of seventeen respondents identified themselves as future teachers, while 884 out of the total 2,023 responded to this section across the consortium. A four-point Likert scale was used to categorize student responses to questions on how the course had increased their motivation to try different math/science teaching strategies, increased their understanding of how to use those strategies, and how likely they were to share teaching ideas from the course with classmates in the following year. In the Studio course, 80-90% of the students gave the two most positive responses to these questions, while ~70% did so out of the larger group.

Beyond the Studio

The Science Studio was offered on a regular basis from Fall 1996 semester through Spring 2000. Since then, scheduling difficulties and other course commitments have prevented the author from teaching it. The challenge remains to recruit other faculty members within the department to teach in the Studio and provide them the requisite opportunities to become familiar with this mode of instruction. The technologies and methodologies of the Studio have, however, had a tremendous impact on introductory science laboratories at NSU. Through the efforts of James Toy, a physics instructor who attended numerous AAPT meetings to be trained in the techniques of active engagement laboratories, *all* introductory physics laboratory courses have been redesigned (including the one for physics majors) so that they make extensive use of microcomputer based data acquisition. The course activities are based on the *Tools for Scientific Thinking* curriculum [6,21] adapted for the TeamLabs equipment. The professional development opportunities afforded by workshops at the AAPT bi-annual national meetings are an easy way for other faculty members to become familiar with the instructional approaches of inquiry learning as espoused in the Studio. Half-day and full-day workshops are available at a very reasonable cost for teachers interested in learning from other professionals engaged in various methods of instruction informed by research on student learning. The author will continue his efforts to encourage other colleagues to take advantage of these opportunities.

Conclusion

The Science Studio course at Norfolk State University has created an inquiry-based, technology-rich learning environment for non-science majors enrolled in an introductory physical science course. The course model combines traditional lecture and laboratory sections and emphasizes active student learning and opportunities for students working in groups to design experiments, gather data, analyze it and communicate their results to their peers. Evaluations indicate that the Science Studio has been successful in reaching many of its goals. The Studio model has potential to be more effective than lecture in changing students' views about science and its personal relevance. Aspects of the studio model, such as the use of MBL, have been adopted widely in introductory physics laboratories at Norfolk State University. An important goal for the future will be to train additional faculty members in active learning methodologies and the technologies that support workshop/studio instruction to sustain this instructional model [22].

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