Presented at the 1996 International Conference on Undergraduate Physics Education (ICUPE)

WORKSHOP PHYSICAL SCIENCE: PROJECT-BASED SCIENCE EDUCATION FOR FUTURE TEACHERS, PARENTS, AND CITIZENS

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July 30, 1996

This paper gives an interim report of a program designed to improve science education for pre-service elementary school teachers and other non-science majors. Building on the success of Workshop Physics [1], this program blends guided-inquiry techniques with student-directed projects. The curriculum is still being pilot tested but preliminary assessment shows that students are quite motivated by the project-based nature of the course. In addition, students appear to show significant improvement in their understanding of the nature of science as is evidenced by the quality of the projects and the questions raised during the project presentations.

INTRODUCTION

The Workshop Physical Science project is a major effort to increase the effectiveness of science education for pre-service elementary school teachers and general non-science majors. The project began in the fall of 1994 with a three-year grant from the Charles A. Dana Foundation that supplied full funding for the initial year and partial funding for years to and three. Since then, additional funding has been secured from both the Fund for the Improvement of Post-Secondary Education (FIPSE) and the National Science Foundation (NSF) which extends the project into a fourth year. This report will describe the status of the project and give a detailed description of the format of the course and the basic philosophy underlying the design of the materials.

The two most important precepts that were axiomatic in the development of this curriculum are:

1. That it is impossible and unrealistic to expect future elementary school teachers to learn all the content they are "supposed" to know in a one year introductory course.
2. That the science skills and knowledge necessary for future elementary school teachers are precisely those that we would like the average parent or citizen to possess, namely, a detailed understanding of the nature of science.

The first of these assumptions comes from a cursory glance at some typical areas that elementary school teachers are supposed to be prepared to teach. According to the recently published National Standards [2], these include aspects of physical science, life science, Earth and space science, technology, social perspectives and the history of science. Mastery of such a diverse range of topics would be difficult even if many courses were taken. However, most colleges and universities typically require only one year of a laboratory science. Attempting to cover such a large and diverse set of topics in one year will likely result in a superficial understanding of facts with no real sense of what science is all about.

The second assumption derives from our belief that children are "natural scientists," with a curiosity to learn about the world that is both powerful and persistent. When parents (or teachers) have a poor understanding of science, they miss an extraordinary opportunity to develop this natural curiosity into an appreciation and understanding of the process of science. Capitalizing on opportunities such as this can only result if both teachers and parents have a firm grasp of science. What's more, understanding the nature of science can only result in a more informed and scientifically literate population. The conclusion is that the instructional goals for future teachers and non-science majors are essentially the same.

In addition to content issues, the National Standards states that "full inquiry involves asking a simple question, completing an investigation, answering the question, and presenting the results to others." Since teachers teach the way they are taught, the only way to assure true inquiry skills is to have them participate in full investigations—from asking the initial questions to presenting the final results. To achieve this, each unit of our curriculum concludes with an student-directed project. These projects culminate in a classroom presentation which affords students an occasion to assume the role of "teacher." We expect significant learning will be achieved when students are given the opportunity to "teach" their classmates.

Allowing students to undertake projects will undoubtedly reduce the amount of content covered in the course. However, the trade-off is a deeper understanding of the process of science and increased confidence in designing scientific investigations. Moreover, since students will have flexibility in choosing their projects, we expect the students to have more interest and enjoyment in this course. Cultivating such positive attitudes about science should not be underestimated as a major goal for this audience.

Having described what we feel to be essential components in the development of a course for future teachers and non-science majors, we list here a few of the major goals of this curriculum.

- To reduce the fear and anxiety that many students feel towards science
- To expose students to a wide range of scientific concepts and principles
- To increase the students' scientific literacy and their ability to think critically as outlined in *A Guide to Introductory Physics Teaching* [3]
- To offer students hands-on experience with computers and other scientific measuring tools
- To help students gain the confidence needed to undertake small-scale scientific investigations independently
- To provide students with opportunities to present and discuss their findings with their classmates

COURSE FORMAT

Initially, each unit was planned to span four weeks, two for core material and two for projects. However, during the first semester of the pilot test, it became clear that that was not enough time. Two weeks was just not enough time for students to fully grasp the concepts presented in the core material phase. Also, since it usually takes one day for students to really begin their projects and the final day is reserved for presentations, there was insufficient time to develop any depth in the projects. This led us to re-structure the course into a far more reasonable six-week per unit time frame.

During core material activities, students work in cooperative learning groups where they make predictions, perform experiments and record their observations. The students are then asked to construct a model to account for these observations. Microcomputer-Based Laboratory (MBL) systems and spreadsheet analyses are used throughout the core material to aid students in making measurements and collecting data.

The mini-research projects are also done in small teams and are meant to place the students at the helm of a scientific investigation so that they learn first hand what practicing scientists actually do. Since students are in charge of the projects, it is hoped that a sense of ownership and pride will develop that will motivate them to understand the project far better than if they were simply reading material in a book. In addition, the requirement of a formal presentation will demand that students develop a complete understanding of the concepts involved.

At the present time, four units have been developed that are consistent with both the content and pedagogy as outlined in *National Science Education Standards*. These units are:

- Motion, Measurement, and Mathematical Modeling
- Light, Color, and Rainbows
- Pressure, Wind, and Weather
- Heat, Temperature, and Cloud Formation

Together, these units comprise enough material for a one-year course. In the future, we plan to develop additional units so instructors have the flexibility to customize the course to complement their own environments. Thus, units that are used in teacher preparation programs may not be the same units used in a course designed to satisfy a general science requirement. At the present time, we are working on a unit entitled *Patterns and Fractals in Nature* [4], and in the future, we plan to develop units on *Sound, Waves, and Music* and *Magnets, Charges and Electric Circuits*. In addition, to expand this course into other areas of science during the next year, we are actively seeking experienced curriculum developers who are interested in co-authoring modules that emphasize aspects of chemistry, geology, and astronomy.

Core Material

During the first three weeks of a unit, students work through a set of guided-inquiry materials which expose them to a common core of related topics. These activities are designed to take them through a learning cycle the main components of which are prediction, experimentation, reflection and resolution. A brief description of these components follows.

Learning Cycle

Prediction—The prediction phase is used to bring forth students' preconceptions. In order to alter a students understanding of a phenomena, it is important that they be made aware of their previous beliefs. As an example, they might be asked to predict what will happen if a beam of white light travels from air into glass. Following their predictions, a class discussion is often instigated, demonstrating that there are (usually) numerous ideas as to what will happen.

Experimentation—Most of the activities are designed for students working in groups of two. There are times, due to equipment considerations, or because of the difficulty of the activity, that students work in groups of three or four. The experimental activities vary widely, but an example would be for them to pass a beam of white light into a piece of glass at different incident angles. Here the students get a chance to see first hand exactly how their prediction compares to reality.

Reflection—After a series of experiments, students are asked questions that require them to think carefully about what they observed. Were their predictions accurate? If not, what underlying aspect of the prediction is at odds with the observations? How can they alter their perceptions so that they have a consistent view of the phenomena? For the example we have been using, they might be asked how the "bending" of the light beam depends on the incident angle of the beam, or whether they would expect similar behavior if the light beam passed from glass into air or from water into glass.

Resolution—To aid students in reaching a resolution, another class discussion is often initiated. This discussion gives the class a chance to challenge and modify ideas until a consensus is reached. By taking part in such a discussion students hear first-hand how a consistent description is constructed by considering how the different ideas account (or fail to account) for the observations. Typically, the consensus represents a good description of the phenomenon under study. In the case of the light beam, students might invent the concept of optical density (although they would probably refer to it as the "bend-ness" or some other obscure name) to determine how much and in what direction the light beam bends.

The role of the instructor during the core material phase is very different than in a traditionally taught course. While students work through the activity guide, the instructor engages students in a series of questions designed to challenge their understanding of the phenomenon. This type of Socratic dialogue instruction is used in a variety of contexts [5] and has been shown to be very effective at increasing student understanding [6].

Student Projects

The final three weeks of a unit consist of student-directed projects. Here the students work in teams of three on a project of their choosing. Although they are given several project suggestions, they are encouraged to develop one of their own. The hope is that students will devise a project based on something that interests them, helping to develop a sense of ownership and increasing their commitment to understanding the project. In practice, we found that during the first round of projects, students are somewhat tentative and are happy to use one of our suggestions. However, by the time they undertake their second project, about one third of student groups are choosing projects of their own design. By the end of the year, over half the groups were working on projects that were in large part, original ideas. This demonstrates an increase in original thought and creativity being used in the course.

Before embarking on a project, each team is required to submit a written proposal. Typically about a page in length, the purpose of the proposal is to launch the students into thinking about how they plan to approach their project and also to give the instructor an opportunity to make suggestions. Thus, if a group is planning a project that is either too easy or too difficult, the instructor can intervene with some ideas on how to modify the project into something challenging.

The final day of the project phase is reserved for oral presentations. Each team is required to give a ten minute oral presentation of it's project with a five minute question and answer period immediately following. This format is similar to that of a scientific conference and challenges group members to defend their work or explain specific points more clearly. One of the most surprising outcomes of these presentations was that the quality of questions raised by classmates increased markedly from the first set of projects to the last. This is a positive sign that students are forming a clear understanding of what science is all about.

When a full class of students embark on independent projects, there are a number of issues that need to be considered.

Equipment—Undoubtedly, there will be a number of groups interested in similar pieces of equipment. We have devised the following scheme for dealing with equipment in our class. First, students must put together an equipment "wish list" describing what they need and why. This is discussed with an equipment manager (or the instructor) to assess how vital these needs are. They are then assigned a box containing the equipment that has been checked out to them and for which they are responsible for returning upon completion of the project. Items that are scarce or expensive are made available on an in-class basis only.

Instructors' Time Allocation—We have found that students will try to monopolize the instructor's time as much as possible. Our solution is to meet with each group for 10 minutes at the beginning of each session. This is the time for the groups to discuss problems they are having and to seek advice from the instructor. After these 10 minute discussions are complete, time can be divided between groups at the instructor's discretion.

Project Group Assignments—We experimented with a number of methods for assigning project groups, including random assignments and allowing students to choose their own. Neither one of these methods were satisfactory, and after consulting with Kenneth and Patricia Heller, we settled on the following procedure. Three member teams are assigned pseudo-randomly with the following caveats. Each group should consist of a “high achiever,” a “middle achiever” and a “low achiever” (of course, this distinction is never made public to the students). Exactly how to define high, middle, and low achievers is not obvious, but the basic idea is to obtain a mix of skill levels in each group. In addition, we do not allow groups to consist of two men and one woman. Combining students in this way usually resulted in good working groups with all members taking part in the project.

ASSESSING STUDENT LEARNING

So far, our preliminary assessments have been only qualitative. One of the most noticeable improvement during the year was the students' ability to analyze their own reasoning for self-consistency. This took place as an obvious attempt from the students to emulate the types of questions posed by the instructor during previous Socratic discussions. Scrutinizing their own reasoning for self-consistency is an indication of good critical thinking (as outlined by Arons [3]), which is one of the major goals of this project.

Another noticeable area of improvement was in the quality of project presentations and the ensuing questions. Although the first series of presentations were reasonably good, there was a definite deficiency in scientific rigor. In addition, due to the lack of subsequent questions, it seemed likely that there was little comprehension of these projects from the rest of the class. However, the final set of presentations showed a significant increase in both the scientific merit and the quality of the questions posed by other students. This indicates an increased awareness of what a scientific investigation entails and an improvement in the level of understanding by the students.

Although we are encouraged by these qualitative assessments, a much more quantitative evaluation is planned during the next two years. First, we will be using a pre and post content exam to assess student understanding of the major topics covered. This will consist of qualitative, multiple-choice questions similar to questions that appear on the *force and motion concept evaluation* [7]. Second, a careful analysis of the projects should yield valuable information regarding student understanding of the process of scientific investigation. Third, a computer log will be set up for each student in which they will answer various questions throughout the year. How they support their answers should give a clue about their critical thinking abilities. Lastly, an attitude survey will be developed to get a sense of student opinions about science.

SUMMARY

The Workshop Physical Science curriculum is an attempt to improve the science education of pre-service teachers and other non-science majors by blending guided-inquiry techniques with student-directed projects. This new course structure is modular in form and gives the students experience with all phases of a scientific investigation, from the initial questions through the final presentation. The four completed units provide enough material for a year-long course and are consistent with topics outlined in the national science standards.

Preliminary assessment reveals that student motivation is very high during the project phase of each unit and that student understanding of the nature of science is much improved. These initial results are encouraging and we are planning a more quantitative analysis of student learning in the final two years of the program.

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[1] Laws, P.W., *Workshop Physics*, John Wiley and Sons, 1997.

[2] National Research Council, *National Science Education Standards*, National Academy Press, 1996.

[3] Arons, A.B., *A Guide to Introductory Physics Teaching*, John Wiley and Sons, 1990.

[4] We are adapting materials developed at Boston University's Center for Polymer Studies entitled *Fractals in Science*.

[5] Workshop Physics, Physics by Inquiry, and Powerful Ideas in Physical Science are but a few curricula using this kind of instruction.

[6] Hake, R.R, *Am. J. Phys*. **15**, 878, 1987.

[7] Available from the Center for Science and Mathematics Teaching, Tufts University.