Design, Development, and Implementation of an Inquiry-Based, Technology-Rich, Science Curriculum

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by

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Abstract

A study was initiated at the inception of the Exploring the Environment (ETE) project to look at critical factors concerning the use of problem-based learning in Earth science classes. During the 1995-96 school year, the *Tropical Poison* module from the ETE Project was evaluated in nine high schools across the country. The module introduced students to authentic environmental issues within the context of an ill-structured problem. The ETE Project Team also conducted one-week workshops for participating teachers -- with five of the nine teachers participating in this study attending the workshop. An "ex post facto," causal-comparative research design was used. Likert data from teacher and student surveys, and end-of-exercise reports written by students were analyzed to seek out causes, relationships, and their meanings**.** Research questions addressed student attitudes toward the understanding of the problem solving process and their perception of their involvement in learning in an inquiry environment. The data were analyzed comparing students' scores by teachers who participated in the week-long workshop, versus those who did not. Students whose teachers had attended a week of professional development prior to this study, had significantly higher attitude scores concerning problem solving and engagement. The same students also had significantly better end-of-module written reports than the students of teachers who did not attend the ETE summer workshop. Though not an experimental design, and the subjects varied as to background and pre-knowledge, this brief study supports the importance of providing professional development for teachers devoted to using inquiry-based methods in science classrooms.

Open-ended, student-centered curricula in which students investigate problems, conduct research, make and support recommendations has received increasing attention. For example, the *Benchmarks for Science Literacy* (AAAS, 1994) cites the growing literature in the area of problem solving and recommends students develop habits of mind encompassing the knowledge, skills, and attitudes supportive of effective problem solving. Among abilities recommended for student development are questioning, seeking answers, displaying curiosity and skepticism, viewing science and technology thoughtfully, using technical tools, and becoming critical thinkers during data interpretation.

The Third International Mathematics and Science Study (TIMSS, 1997) provides some insight concerning the approach to math and science teaching in the U.S. Analysis of the results suggested that U.S. high school math and science classes try to cover too wide a variety of subjects and that teachers rarely have the time to teach in any depth. Teachers in other countries teach to a more narrow range of subjects and can afford to get into depth. Analysis of the TIMSS Study showed that U.S. mathematics and science textbooks included far more topics than was typical internationally, but went into less depth. Dr. Neal Lane, Director of the National Science Foundation, suggests classrooms place more emphasis on inquiry-based learning (Lane, 1996).

Inquiry-based environments provide students opportunities to generate and revise their thinking in interdisciplinary contexts. Doing this takes a great deal of time, but allows students to learn in depth. To be of use, information needs to be associated with prior knowledge and then integrated into larger knowledge structures. Such structures require students to do more than follow established sets of rules; they need to participate in the development of their own knowledge. Knowledge structures that relate previous and new knowledge with procedures used in the development of those structures evolve slowly, but they are fundamental to understanding. (Pallrand, 1996).

Problem-based learning (PBL) methods, a variant of inquiry-based learning, enable students to practice connecting what they already know with what they are learning. Students can call upon and organize what they have previously learned; then, as they face new information, they can begin to reformulate their ideas--accommodating and integrating the new information with the old. In this way, knowledge development occurs through a process much like that found in the practice of science itself (Pallrand, 1996).

PBL facilitates inquiry-based methodology by allowing students to identify problems, conduct research into problem areas, interpret and analyze data, and demonstrate understanding through the creation of an artifact or presentation. PBL has been used in medical schools to teach students to think critically and integrate and apply knowledge in an inquiry-based approach (Barrows, 1988; Higa, Lindberg, Anderson, Felentti, & Brandon, 1995). PBL research has suggested that these environments enhance intrinsic subject-matter knowledge, foster long-term knowledge retention, and facilitate self-directed, long-term learning skills (Norman & Schmidt, 1992).

Higher order thinking on students' part is a desirable, often elusive, but highly sought after occurrence. Instead of offering maturing students opportunities to exercise independence, cultivate thinking skills, or engage in the pursuit of knowledge, teachers spend more time lecturing to them on topics that vie for air time in an already crowded curriculum (Sharan & Sharan, 1992). PBL methods emphasize "open-ended questions" that require higher-order thinking (Gallagher, Stepien, & Rosenthal, 1992). Often referred to as "ill-structured," PBL scenarios confront students with a situation that requires more information than is immediately available. Problem definitions may change as investigations continue; and there is no absolutely "right" answer.

Recent PBL research at the secondary level addressed the emphasis in education in providing students with opportunities to solve problems and conduct student-directed investigations. A study by Gallagher, Stepien, and Rosenthal (1992) suggests that teaching techniques using ill-structured problems as the center of learning may be the most appropriate way to prepare students for the kinds of challenges they will face as adults. Research has suggested that students in environments similar to PBL (group investigations) matched or exceeded progress of students in traditional classes (Sharan & Sharan, 1992). Sharan and Sharan also found that students engaged in group investigations were more adept at demonstrating analysis and application of knowledge to new problems, and that these environments enhanced the intrinsic motivation to learn.

While PBL research suggests increased student engagement, metacognitive growth, and long-term knowledge retention, a growing body of literature points to teacher preparation as one of the keys to success. Teachers and students used to traditional instruction may be in for some surprises. It takes time, patience and a willingness to accept risk and uncertainty to begin using inquiry-based classroom methods. It may take teachers one to two years to feel confident with these approaches to learning. Students, for example, will likely be very reluctant to take risks on their own–especially if they are used to having the objectives, assignments, and problems handed to them. If they are used to standard, objective tests, then students may dwell more on what they have to do to "get their grade" than in readily adapting to the PBL format (Myers, Purcell, Little, & Jaber, 1994).

Airasian and Walsh (1997) caution that constructivism provides a useful model of knowing and learning that is descriptive but not prescriptive. They point out that constructivist orientations take time for teachers and students to learn to perform in these classrooms; teachers need new questioning and responding skills; and students have to learn to think for themselves. To do this, they state: "Teachers will have to serve as initiators of activities that will evoke students' interest and lead to new constructions and as critics of the constructions that students produce" (p. 448). Airasian and Walsh also point out that teachers and schools will have to question whether to cover a large amount of content at a shallow level or to cover a smaller amount of content in great depth.

Others suggest teachers receive professional development workshops dealing with classroom organization, cooperative learning strategies, discussion skills, and assessment strategies (Sharan & Sharan, 1992). Sharan and Sharan recommend establishment of a new classroom climate that encourages student interaction, and exchange of information between mixed-ability groups. In addition, Norman and Schmidt (1992) discuss the importance of teacher feedback during problem solving situations. Finally, research suggests that subject-matter expertise, commitment to students' learning and to their personal lives in an authentic way, and the ability to speak in language used by students are all ingredients for success in problem-based curricula (Schmidt & Moust, 1995). Schmidt and Moust also recommend teachers create an atmosphere supporting an open exchange of ideas.

A study was initiated at the inception of the Exploring the Environment (ETE) project to look at critical factors concerning the use of PBL in Earth science classes. The modules were delivered via the World Wide Web. In addition to the use of inquiry-based methods, the ETE modules incorporated the use of NASA remote sensing images as a classroom resource. Of particular interest in this study was the impact of teacher training in using PBL, student engagement and motivation, and the quality of students' products. ETE was designed by a team consisting of biologists, geologists, and educators as a supplement to Earth science courses. Each module within ETE is self contained and addresses the increasing interaction between the scientific and human dimensions.

METHODS

Subjects

During the 1995-96 school year, the ETE Project was evaluated in nine high schools across the country; over 200 students participated. Due to the nature of this project, it was not possible to meet the requirements for an experimental design. Participating teachers were chosen after submitting applications to participate in an alpha test. Teachers had to have World Wide Web access and agree to use problem-based learning methodology. Participants used the modules in a variety of classes, including biology, ecology, algebra, and chemistry. Students ranged from grades 9 through 12 and varied in background and pre-knowledge. Schools came from across the continental United States, representing urban, suburban, and rural settings. All but three of the schools used the ETE modules in elective classes. Because of the non-random nature and the degree to which classes varied by age, experience, course of study, and teacher background, the ability to generalize the findings beyond this study is limited.

Intervention

The ETE *Tropical Poison* module introduced students to authentic environmental issues within the context of an ill-structured problem. This web-delivered scenario asks groups of students to consider whether habitat destruction in the tropical rain forest is a threat to poison dart frogs (http://www.cotf.edu/ETE). Available to students were a standard problem solving model, and on-site resources -- to include satellite coverage of selected rain forest areas -- spanning a period of six years. Student-directed research lasted a minimum of five weeks. Working cooperatively, students engaged in problem-based activities requiring them to formulate problem statements, collect and analyze data, then prepare and present their findings, solutions, or recommendations. It should be pointed out that this particular module has a wide scope, providing students opportunity to find ownership through the identification of a problem that appeals to their interest. Typical problem statements revolved around biodiversity or habitat destruction.

The ETE Project Team also conducted one-week workshops for participants. Five of the nine teachers participating in this study attended the workshop. Workshop goals addressed the use of problem-based learning, remote sensing, and alternative assessments. A major objective was in getting teachers to consider that inquiry-based classrooms differ in these respects: student to student interactions are normally more frequent than teacher to student; teachers have to create and maintain an atmosphere in which students feel free to openly discuss issues; students must feel that their ideas are valued; it takes time to acquire, analyze, discuss, and understand the content; and students need to develop discussion, research, analysis, and communications skills. As opposed to a traditional whole class environment, teachers in inquiry classrooms focus on facilitating greater student effort at thinking critically, analyzing, communicating, making logical arguments, and working cooperatively in groups. While teachers' perceptions of this workshop are not a focus of this paper, most ranked the training as among the very best they had ever attended.

Design

A causal-comparative research design was used and was "ex post facto" in nature. The data were collected after all the events of interest occurred. This "case study" data provided useful anecdotes or examples to illustrate more generalized statistical findings. The data, consisting of teacher and student surveys, and end-of-exercise reports were analyzed to seek out causes, relationships, and their meanings**.** Perhaps the most vivid insights are from anecdotal evidence. This approach often brings to light important variables, processes, and interactions that deserve more extensive attention. These provide clues and are often the source of fruitful hypotheses for further study.

The main weakness of any ex post facto design is the lack of control over independent variables. Within the limits of selection, the investigators have taken the facts as they were found -- with no opportunity to arrange the conditions or manipulate the variables that influenced the facts. To reach sound conclusions, therefore the investigators considered possible reasons or parallel positions which might have accounted for the results.

Instruments and Data Analysis Techniques

Student end-of-module questionnaires with Likert measures

Students completed a questionnaire that addresses issues relevant to the development of the modules. Examples include difficulties they have encountered, sections of the modules that were especially beneficial, and their suggestions for modifications. The end-of-module questionnaires contained Likert scale response forms with space for written elaboration. Differences between classes were analyzed using ANOVA. For purposes of this analysis investigators focused on those questions dealing with motivation and engagement.

A blind review of students' written products

Students were required to complete research that followed the problem-solving process. Three science educators unconnected with the project conducted a blind review of the students' written reports. Differences between classrooms were analyzed using ANOVA. Interrater reliability was established through a process of forced consensus. The reports were graded on five areas. First, is there an appropriate, well defined problem statement? Second, are methods of investigation reasonable; are sources credible? Third, is a logical analysis of data presented? Fourth, is a valid summary or conclusion presented, based on sound argument? And fifth, are the recommendations reasonable and appropriate to the real world? (See Appendix A for the complete form.)

Teacher end-of-module questionnaires and teacher interviews

Teachers completed a questionnaire that addressed issues relevant to the implementation of the study. The questionnaires asked for replies concerning difficulties encountered, module design, and facilitation of inquiry-based classrooms. Teacher questionnaires were further supplemented by site visits or by telephone interviews. These questionnaires were surveyed for anecdotal information that illuminated findings from the other two areas.

RESULTS

Did students develop a better understanding of the problem solving process?

One means of looking at problem solving was to examine students' self-reported opinion of increases in problem solving abilities. First, investigators looked at a question concerning problem solving: are there significant differences between the Likert measures of students' attitudes -- at different test sites -- towards understanding of the problem solving process? A score of 1 indicated "Strongly Disagree," a score of 4 indicated "Strongly Agree." The results of the ANOVA test in Table 1 showed that students in schools 4 and 6 had significantly different attitudes toward development of understanding of the problem solving process.

Many comments from the students at schools 4 and 6 indicated they had already been associated with problem solving models. This may account for their failure to perceive progress in learning about problem solving. It should be pointed out that both of these schools accounted for the 9th graders in the study. School 4 was a magnet school for minority students in an urban area; school 6 was a private, suburban school near a major metropolitan area. The teacher in school 4 reported frequently using problem-based learning. A significant comment from him was that hardware problems contributed to a continuing sense of frustration. The teacher in school 6 stated that she was unfamiliar with the content of the module -- making her feel uncomfortable. She also expressed an interest in more training concerning the classroom use of PBL.

To look further into what was happening on this question, as well as other research questions, we examined time on task, grade level, course, and access to computers. None of these variables indicated significant differences between the schools. Teacher training, however, provided some insight into what was happening with the questions. By looking at students' answers to question 2 based on whether or not their teacher had attended the summer workshop, a significant difference was noted once again (Table 2).

Were students more involved in an inquiry environment?

The next question for analysis concerned whether or not students felt they were MORE INVOLVED in using the ETE modules than normally. A school by school comparison showed that the students in schools 4 and 6 did not feel they were more involved. That table closely matched Table 1 and is not shown here. Table 3 shows statistically significant differences in students' attitudes based on whether or not their teacher had attended the ETE summer workshop.

Students' scores on end-of-module written reports.

The next analysis addresses students' scores on the written report generated at the end of the module. The blind review was conducted by three science educators. To achieve reliability the reviewers spent time with the investigators determining the criteria for grading, after which the reviewers spent time working through several test cases. The reliability score for the overall evaluation was .92, determined using Spearman Rank Correlation. Statistical analysis of the reports' scores by school is provided in Table 4.

First, note that two schools are absent in the above table that were present in Table 1. This is because nine schools participated with the *Tropical Poison* module and completed the questionnaire, but only seven schools participated by also generating a student report. Second, there was a prominent anomaly in Table 4. The anomaly was that School 6 had the highest scores on the blind review. This comes despite the fact that these students were 9th graders competing with upper classmen from across the country. They were also the ones who felt they had not gained in problem solving ability or that they were more involved with this module than normally.

The data was also analyzed comparing students' scores by teachers who participated in the week-long workshop, versus those who did not. Analysis of the results are provided in Table 5.

The students of those teachers attending the ETE workshop had significantly higher scores than the students of the teachers not attending. This result is even more significant when noting that School 6's students outperformed all other students, and their teacher had not been to the training.

DISCUSSION

Through the *Tropical Poison* module, students investigated the decline in amphibian populations world-wide. Encountered in their research were the issues of biodiversity, the gene pool, and habitat destruction. Because this information was on the World Wide Web, student research groups were able to seek information from all over the world. They could visualize recent satellite imagery, measure changes in the frog's habitat, and make inferences concerning future habitat losses.

Many students elected to act on new information. One group in Seattle sent a message to the NASA Classroom of the Future with information about the production of "treeless paper." Their recommendation was that NASA agencies should use only this process. A group in Atlanta sent a letter to their US senator concerning the policy of a South American country toward native peoples. These are but two examples of the level of authenticity students can experience during their project as a result of using timely, relevant materials on the World Wide Web.

Students' attitudes toward PBL also proved interesting. Though many were unfamiliar with such an approach, many students felt that the *Tropical Poison* module was a challenge. Some commented that the process made them think. Other students were suspicious of the approach; they wondered how one could take a position regarding a problem and then be allowed to change what had been said originally. Still others were uncertain about what was expected; they were uncomfortable with instruction that relied on what they thought and not so much on what the teacher said.

An overriding question looked at in the design of the questionnaires was whether or not the inquiry-based or PBL-based environment used in the case study was a contributor to increasing students' problem solving skills or in their engagement. While all teachers reported favorably on the experience, it was deemed important to see whether the students would render the same report. There were many variables pointing out the striking differences between and among schools--so many that it would be hazardous to generalize beyond this study. Indicators appeared to suggest, however, that those teachers who attended professional development classes addressing PBL, had students who professed learning more about problem solving and thought they were more involved during PBL than in regular classes. The same students also had significantly better end-of-module written reports than the students of teachers who did not attend the ETE summer workshop.

While not within the scope of this study, there is still the problematic anomaly of the 9th graders who had the highest scores on the written report, yet did not report gains in problem solving ability or engagement. The investigators looked at various hypotheses to explain this occurrence. It may simply be that these students were fortunate in having the resources and environment necessary for success. At this point, however, the matter is purely speculative and may point to a fruitful area for further study.

Educational Importance

The investigators in this study support the national standards for science education and believe they offer a means of motivating students and providing for in-depth understanding of science content and process. This brief study raises the issue of how important it is to provide professional development for teachers devoted to systemic change in education. At a recent inquiry-based workshop put on by the authors of this paper, one high school teacher remarked: "I have to be brutally honest. It is all right for you to sell constructivist, inquiry-based environments, but when we have to prepare students to score well on state-wide standardized tests or the ACT or SAT, you don't have the luxury of experimenting with new methods." This teacher's remark reflects the dichotomy faced in schools across the country as they wrestle with standards supporting "less is more" and inquiry-based methods. As Airasian and Walsh (1997) point out, implementing constructivism in the classroom will be considerably more challenging than thought.

Teachers' roles, however, may be the essential ingredient in effectively using technology and inquiry-based methods in the teaching-learning scenario. We have presented means for teachers to use in helping students engage in learning and reaching new levels of understanding. This paper reinforces the role of the teacher as the primary agent in successful teacher-student interactions. If anything, teachers' roles will become even more important. As Newman, Griffin and Cole (1989) state: "We have seen that the process of instruction cannot be reduced to direct transmission of knowledge, nor are creative learning processes necessarily entirely internal to individuals" (p. 112).

Students need time for exploring, making observations, taking wrong turns, testing ideas, doing things over; time for collaboration, collecting things, and constructing physical and mathematical models for testing ideas. They also need time for learning prerequisite mathematics, technology, or science they may need to deal with the questions at hand; time for asking around, reading, and arguing; time for wrestling with unfamiliar and counterintuitive ideas and for coming to see the advantage in thinking in a different way (AAAS, 1994). Teachers need time too —— time to reclaim the skills of curriculum development and instructional creativity. Time and resources are needed for teachers to develop and deliver a curriculum, to train and work together, to restructure science classroom teaching practices to meet the diverse needs of students.

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Appendix A

Blind Review Form

PROBLEM STATEMENT

The problem is well defined.

The problem statement is appropriate (useful for research).

The problem statement is valid (relates to the Brazilian rain forest and the influences upon it).

METHODOLOGY

How/where was the data obtained - an explanation.

The methodology is duplicable (reliable).

Sources are reasonable/valid/credible...bibliography.

ANALYSIS OF DATA

A premise relating to the problem statement is developed.

A logical analysis is presented.

Supporting facts are organized such that conclusions can be adequately drawn.

SUMMARY & CONCLUSION

The argument is sound.

A reasonable summary is stated.

Conclusions are valid.

APPLICATION

Reasonable and appropriate connections to the real world.

Obvious connections are not omitted or overlooked.

Includes problem solving suggestions.

Total/Average______