AN INVESTIGATION OF PROJECT-BASED LEARNING AND COMPUTER SIMULATIONS TO PROMOTE CONCEPTUAL UNDERSTANDING IN EIGHTH GRADE MATHEMATICS

by

ALLEN SYLVESTER

B.G.S., University of Kansas, 1995
M.S., Kansas State University, 1997

AN ABSTRACT OF A DISSERTATION

submitted in partial fulfillment of the requirements for the degree

DOCTOR OF PHILOSOPHY

Department Of Secondary Education
College of Education

KANSAS STATE UNIVERSITY
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Abstract

The goal of this study was to explore the use of interdisciplinary PBL projects for teaching mathematical concepts according to NCTM (2000) goals for mathematics instruction. This study sought to answer the question: what are the teaching issues and evidence of student learning of mathematical concepts over a series of three interdisciplinary PBL projects involving STELLA™ modeling software which are designed to engage students, integrate technology, and provide a context for learning mathematics based on the 5 NCTM (2000) goals? HyperStudio™ was used as a communication tool with which students built artifacts of understanding.

This study was a naturalistic case study employing videotaped observations, interviews, student-peer reviews and student generated artifacts of learning as data sources. Data were categorized into two variable clusters: Teaching and Learning.

Implementation issues for three computer-based PBL simulations are discussed. Themes that emerged from analysis of the data are grouped into teaching themes and learning themes. Themes relating to teaching include the struggle to form a community of learners, relevancy of the simulations to middle school students, need for group-worthy projects, helping students balance creativity and content, lesson adaptation, and critical review and student reflection on constructive feedback. Findings of the study suggest the students were able to meet a majority of the expected content goals. Themes relating to learning include the struggle to find a balance between creativity and content, ownership and control, engagement with the simulations, and students' ability to think and express themselves mathematically. Recommendations are made for teachers who wish to implement PBL, simulations, and similar teaching strategies and for researchers who are studying similar learning environments.

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Dedication

I dedicate this dissertation to the following:

- To all teachers – for your daily struggle to do what is best for children - May there soon come a day when the world values you as highly as you deserve.
- To my mother, Nola, who taught me to value education and to stand up for what is right.
- To my father, Elgene, who taught me that I could do anything I set my mind to.
- To my wife, Debbie, for her infinite patience and encouragement.

And finally, to David Barnes – until you have one of your own, this one's for you!

CHAPTER 1 - Introduction

According to The Third International Mathematics and Science Study (TIMSS 1996), American eighth grade students are below average mathematically, when compared to their contemporaries in 23 other industrialized nations. Three years after the TIMSS results were released, the TIMSS study was replicated. The "TIMSS-R" as this retesting was later named, showed that while U.S. eighth graders' scores had slightly increased in the three years between the tests, no statistically significant increase was found when compared with the 1995 scores (TIMSS 1999). The fundamental problem remains: test scores of eighth graders who study mathematics in the United States do not compare favorably with those in other nations. While this statement is alarming, it is consistent with findings from the National Assessment of Educational Progress (Allen et al., 1996). Secada (1992) and Silver, Strutchens, and Zawojewski (1997) also showed substantial gaps in performance, especially on tasks that assess conceptual understanding, mathematical reasoning, and problem solving.

In an attempt to explain the performance gap, TIMSS analyzed the leading curricula currently used in six other nations which scored significantly higher on TIMSS than did the United States. These countries include Australia, the Czech Republic, Hong Kong, Japan, the Netherlands, and Switzerland. The study indicated that K-8 curricula in the United States tend to be overly repetitive in their coverage of mathematics concepts. The TIMSS study found that of the topics presented in a typical U.S. 8^{th} grade mathematics textbook, only 25 percent of topics are new since 4^{th} grade, compared to 75 percent in the other countries' textbooks (TIMSS 1999). TIMSS also found that U.S. mathematics curricula are not as cognitively demanding as those of the other industrialized nations. Emphasis within U.S. mathematics curricula is placed on so called "basic skills," which tend to be arithmetic rather than algebraic, with little emphasis placed on conceptual understanding or complex problem solving. The findings of the TIMSS-R analysis are consistent with those of Flanders (1987) and Freeman and Porter (1989).

The TIMSS study found striking consistencies in the method of instruction among U.S. mathematics classrooms. Compared to the other industrialized nations, eighth grade classrooms in the U.S. tend to emphasize low-level cognitive processes. Goodlad (1984) and Stodolsky

(1988) note this same lack of attention to higher-order thinking processes and conceptual understanding.

Bransford, Brown, and Cocking (1999) point out that conceptual understanding is an important component of proficiency in mathematics. Those students who receive instruction limited to memorization of facts and procedures (lower level cognitive processes) have a more fragile understanding of mathematical concepts than do those who receive conceptually based instruction. Schoenfeld (1998) indicates that mathematics makes more sense and will be better remembered and applied when new concepts are connected to existing understandings.

In 2000, the National Council of Teachers of Mathematics (NCTM) published its "Principles and Standards for School Mathematics" (NCTM, 2000) as a set of recommendations "grounded in the belief that all students should learn important mathematical concepts and processes with understanding" (NCTM, p. 20). NCTM Standards 2000 call for a learning principle according to which "students must learn mathematics with understanding, actively building new knowledge from experience and prior knowledge." Mathematics students should engage in more real-world problem solving, where situations are complex or ill structured.

Project-Based Learning

A teaching method sometimes referred to as "Project-Based Learning" or PBL, can be a powerful tool in providing students with the necessary complex, real-world problem solving situations called for by the NCTM Standards. Krajcik, Blumenfeld, Marx, & Soloway (1994) specify that problem solving with PBL has five key features, which I designate as PBL Goals (see Table 1).

Table 1. PBL Goals, from Krajcik, Blumenfeld, Marx, & Soloway (1994).

A "driving question" which is authentic and engaging, and which organizes the scenario being studied.
Student generated artifacts, or products, which address the driving question and are presented to an authentic audience.
Investigation which requires student collaboration and research over an extended time period.
A "community of inquiry" (students, teachers, and members of society).
The use of technology-based cognitive and communication tools.

Project-Based Learning increases student motivation because the projects present problems which are couched in a real-world context that the students are likely to encounter in their lives or future careers (CGTV, 1992). As mentioned in NCTM's Standards, these problems are ill-structured. This means the problems require information not initially or explicitly provided, and therefore require the learner to identify needed information, and engage in information search and collection (Nelson, 1999).

Unlike traditional classroom structures, Project-Based Learning's rewards are intrinsic and non-competitive. Ames (1992) noted that extrinsic and competitive rewards lead to learning and demonstrating just enough to get by. Students in Project-Based classrooms, with the focus on authentic performance, collaboration, and student choice exhibit a higher degree of motivation (Blumenfeld et al., 1991).

Modeling

In contrast to mathematics education, current science education has moved toward the building of models for the purpose of understanding complex real-world phenomena. For several years, the focus has been on data collection, data visualization, modeling and reporting (e.g. Soloway, Krajcik & Finkel, 1995). This modeling process requires the learner to make connections between variables, and to compare the results with observations of the real world (Spitulnik et al., 1995).

Ost (1987) describes a type of theoretical modeling that can be useful in teaching mathematics and science. He suggests that students should create theoretical models that have a correspondence to reality, showing graphical interrelationships between components that are traditionally represented by algebraic formulae. These models allow for the introduction of the concepts of feedback and change in a way not traditionally available to students due to the complexity of the mathematics involved.

White (1993) describes a process by which middle school students learn to model Newtonian physics interactions. Traditional approaches to learning physics have tended to rest heavily upon the use of equation solving and algebraic transformations. As stated by White, "They have learned how to manipulate formal abstractions in order to solve problems, but they have not learned the meaning of the abstractions" (White, 1993, p. 3). Students in White's study were asked to interact with a series of computer models that incorporated concepts, causal relationships, and representations of a real-world scenario. By experimenting with these models, students were able to link abstract representations of computation to the dynamic phenomena being observed. Through this process, abstractions became more meaningful and concrete. This is a kind of "performance of understanding" (Perkins, 1992): an opportunity designed to facilitate deep conceptualization, and may support individual differences in learning style (Gardner, 1993). Brown, Collins, and Duguid (1989) suggest that learning performances such as this ought to be situated as much as possible within real-life contexts.

Computer-Based Dynamic Modeling

Computer-based dynamic modeling involves many of the characteristics of White's (1993) study, such as thoughtful analysis, cause-and-effect reasoning, and mindful synthesis (Forrester 1968, iseeSystems, 1992; Mandinach & Cline, 1994). Originally described by Forrester (1968), dynamic modeling software has recently become available to secondary school students. Software such as STELLA (iseeSystems, 1992), IQON (Miller et al., 1993), and MODEL-IT (Highly Interactive Computing Group, 1995) provides a user-friendly design space that allows students to create interactive models, which are "runnable" (iseeSystems, 1992).

In dynamic modeling software, a model is created with the primitives of "stocks," "flows," "converters," "and "connectors." Stocks illustrate levels or quantities within the simulation. Flows control the increase or decrease of the quantities held in stocks. Converters regulate flows according to factors, rates, or ratios that influence the flows. Connectors show directional relationships among the other three primitives within the model (See Figure 1).

Figure 1. An example illustrating all four STELLA™ primitives.
((Used with permission of ISEE Systems)

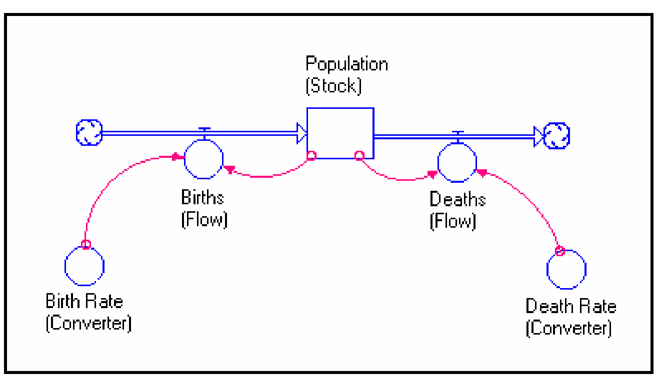

Figure 1 illustrates the use of the four STELLA™ primitives. The number of organisms in a given area (population) can be represented by a stock. Births are simulated by a flow of organisms into the stock population, deaths as a flow out of the stock population. Birth and death rates are converters which influence the flow of organisms into and out of the stock population, but which are influenced in turn by the number of organisms in the stock population. As learners develop deeper understanding of the factors influencing birth and death rates, other converters may be connected to the birth and death flows to represent concepts such as predator-prey relationships, disease, environmental factors, and many others. The computational mathematics required to complete a model of this complexity is "hidden" behind the graphical relationships of stock-flow-converter, allowing learners to focus upon the conceptual complexity of the relationships being studied.

Once a model has been built, dynamic modeling software enables learners to run their model and observe the output in tables, graphs, or animations. At run time, the learner can change the variable values to test the effects on the rest of the system. To Giordano et al. (2003), this kind of modeling forms the bridge between knowledge of mathematics, and the application of that knowledge to solve authentic problems. For these reasons, in this study I chose to detail middle school mathematics students' use of computer-based dynamic models as they grapple with a series of three authentic problems.

Statement of the Problem

If mathematics instruction is to educate U.S. students to compete on an international level while remaining within the principles outlined in Standards 2000, attention must be focused toward providing meaningful and powerful mathematics education. Where traditional instruction has emphasized computational facility, the focus must be shifted toward a broad, integrated view of mathematics (NCTM, 1989). The NCTM (2000) has provided five goals toward meeting this shift in focus which I will refer to as NCTM Goals (See Table 2).

Table 2. The five goals for mathematics instruction from NCTM (2000).

learning with understanding;
technology integration;
diversity and flexibility;
reflection;
collaboration.

Technology integration, as mentioned in NCTM Goal 2, provides support for a wider appreciation of mathematics than was previously available to students. Problems in basic computation tend to inhibit students' conceptual growth and their appreciation of mathematics. (NCTM, 1989).

"The calculator renders obsolete much of the complex paper-and-pencil proficiency traditionally emphasized in mathematics courses. Topics such as geometry, probability, statistics, and algebra have become increasingly more important and accessible to students through technology" (p. 66).

Classroom activities should provide opportunities to work both individually and in collaborative groups, as in NCTM (2000) Goal 5. Working in groups should provide a sense of community, where students express their ideas and share skills. In addition, working in groups makes positive use of the middle school student's affinity for social situations. Working in groups provides a context for learning, and can provide a scaffolding, or strong conceptual basis, for reconstructing their knowledge at a later time (NCTM, 1989).

Care must be taken to promote understanding among all members of a diverse learning community with multiple learning styles and different levels of prior knowledge, in accordance with NCTM Goal 3. The use of dynamic modeling has shown to be a valuable tool in providing this sort of diverse educational experience in science classrooms (Ost, 1987; White, 1993), but little has been done to study its use within the mathematics classroom.

If we teach students in a cross-curricular, problem-based learning environment, with emphasis placed on the five NCTM (2000) goals for mathematics instruction, and utilize the power of dynamic computer models, is there evidence the students are learning mathematical concepts?

Goal of the Study

The goal of this study is to explore the use of interdisciplinary PBL projects for teaching mathematical concepts according to NCTM (2000) goals for mathematics instruction. These projects involved students in using the STELLA™ and other dynamic modeling software.

In this study, I qualitatively analyze three interdisciplinary PBL-based projects conducted in an eighth grade mathematics classroom. I began with initial guiding question: What are the teaching issues and evidence of student learning of mathematical concepts over a series of three interdisciplinary PBL projects involving STELLA™ modeling software which are designed to engage students, integrate technology, and provide a context for learning mathematics based on the 5 NCTM (2000) goals?

The data gathered in this study can be characterized as belonging to two variable clusters: teaching, and learning. Two sub-questions were developed relating to the two variable clusters:

> What are the issues related to teaching mathematics concepts in a technology-rich, interdisciplinary PBL project which follows the 5 NCTM (2000) goals?
>
> What are the issues related to learning mathematics concepts in a technology-rich, interdisciplinary PBL project?

For each project, as described in Chapter 3, the critical issues surrounding the PBL nature of the project, the math concepts being studied, and the technology tools being employed are enumerated. Themes emerged during the analysis of the data, and are presented in Chapter 5.

Significance of the Study

Steed (1992) lists several advantages of modeling as (among others), enabling real-world phenomena to be explored without sophisticated mathematical knowledge. These models tend to reflect the mental models of the learner, providing an opportunity for formative evaluation during the learning process.

This study will be of significant interest to educators, especially those interested in the use of technology as a point of integration with other content areas. Science and mathematics educators may find their content areas effectively combined in the study of "real-world" phenomena in a setting that is safe and more easily manipulated than a traditional lab setting. Dynamic modeling software provides an opportunity to study phenomena that are not easily observed, such as Newtonian physics (White, 1993), genetics (Simmons & Lunetta, 1993; Finkel

& Stewart, 1994; Finkel, 1996), and environmental impacts (Jackson, Stratford, Krajcik, Soloway, 1995; Hi-CE, 1994). In addition, dynamic modeling can integrate mathematics courses with social studies curricula through investigation of social and population dynamics (Forrester, 1968; Ronen, Langley, & Ganeil, 1992). Educators also will be interested in the impacts and implementation issues surrounding interdisciplinary PBL projects in a middle-school classroom, and the effectiveness of the 5 NCTM (2000) recommendations for learning with understanding.

Teachers and school administrators with an interest in moving toward more constructivist teaching practices such as project-based learning will be interested in this study, as it is an important addition to the body of research surrounding project-based learning in an age of high stakes testing. There is a distinct lack of research on how students in PBL classes fare on high-stakes assessment as compared to "teaching to the test." While this study makes no effort to study standardized testing, it does provide evidence of the mathematical concepts and standards students learn in a PBL setting.

Boundaries of the Study

This study is a single-case study. The case involves students in eighth grade algebra classes, in a Midwestern city. The simulations students worked with in this study focus on those real world scenarios that can be represented by linear and nonlinear systems. In this case, I was both the teacher and the researcher. Three investigations were limited to approximately 4-6 weeks of class time each, for a total of approximately fourteen weeks (70 hours) of class time during a 2-semester period.

Definition of Terms

<u>Authentic Audience</u>: An audience which is outside the students' classroom. (Brown, Collins & Duguid, 1989).

<u>Conceptual Knowledge</u>: interrelationships between and among knowledge elements, and how they function (Anderson & Krathwohl, 2001).

<u>Dynamic Model</u>: A model which involves change over time.

Factual Knowledge: basic knowledge elements of a given domain which are needed to solve problems within it (Anderson & Krathwohl, 2001).

HyperStudio™: A software package from Sunburst Technologies which allows users to develop multimedia presentations using "cards" and "stacks" of cards.

HyperStudio "Card": One page of a HyperStudio™ stack.

HyperStudio "Stack": A presentation made of several HyperStudio™ "cards" with some sort of navigational linkage between the cards in the stack.

Learning with Understanding: the combining of factual, procedural, and conceptual knowledge (NCTM, 2000).

Procedural Knowledge: knowledge of the steps required to do a task (Anderson & Krathwohl, 2001).

Scaffolding: A process by which a knowledgeable individual helps a less knowledgeable learner build on prior knowledge by providing supports to facilitate the learner's development of new knowledge and experiences. (Bransford, Brown, & Cocking, 2000).

STELLA™: A software package developed by ISEE Systems which allows the user to develop time- and process- based simulations (dynamic) for education and research.

Workable Solution: A solution which adequately solves a problem in a simulation. It may or may not necessarily be the best or most elegant solution.

CHAPTER 2 - Review of the Literature

> Imagine a classroom, a school, or a school district where all students have access to high-quality, engaging mathematics instruction…The curriculum is mathematically rich, offering students opportunities to learn important mathematical concepts and procedures with understanding. Technology is an essential component of the environment. Students confidently engage in complex mathematical tasks chosen carefully by teachers. They draw on knowledge from a wide variety of mathematical topics, sometimes approaching the same problem from different mathematical perspectives or representing the mathematics in different ways until they find methods that enable them to make progress. Teacher's help students make, refine, and explore conjectures on the basis of evidence and use a variety of reasoning and proof techniques to confirm or disprove those conjectures. Students are flexible and resourceful problem solvers. Alone or in groups and with access to technology, they work productively and reflectively with the skilled guidance of teachers…they value mathematics and engage actively in learning it. (NCTM, 2000, p.3)

If mathematics education is to achieve the goals set for it by the National Council of Teachers of Mathematics, a dramatic change is necessary. No longer is it sufficient to memorize facts, apply formulae, and get the right answer. The NCTM (2000) has set five goals for the future of mathematics education:

1) learning with understanding;
2) technology integration;
3) diversity and flexibility;
4) reflection; and
5) collaboration.

This study investigates the use of one kind of technological and curricular method for supporting those five goals. Specifically, this study describes the teaching issues and evidence of student learning of mathematical concepts over a series of three interdisciplinary PBL projects involving STELLA™ modeling software which are designed to engage students, integrate technology, and provide a context for learning mathematics based on the 5 NCTM (2000) goals.

In this chapter I discuss the general state of mathematics education in the U.S., modeling in mathematics instruction, project-based learning, dynamic modeling software such as STELLA™ in mathematics classrooms, and theoretical perspectives.

The state of mathematics in the U.S.

The Trends in International Mathematics and Science Study

The Trends in International Mathematics and Science Study was an assessment of mathematics and science knowledge developed by the International Association for the Evaluation of Educational Achievement. It was designed to compare the educational progress of participating countries in fourth and eighth grade. In addition to the assessment, TIMSS included a questionnaire about the logistics of teaching, school policies, teacher preparation and background. The 1999 version of TIMSS included an in-depth video analysis of actual teaching, as well as a textbook comparison.

TIMSS-1 and TIMSS-2

In 1995, 45 countries including the United States tested their K-12 school children at five different grade levels. This test was to provide policy makers, curriculum specialists, and researchers with a base of data with which to better understand educational performance on a global scale. The performance of eighth grade students is of particular interest, as this dissertation research took place in an eighth grade mathematics classroom. Eighth grade students in the United States scored below the international (mean) average (TIMSS, 2000).

In 1999, researchers conducted another test, called the TIMSS-2, to provide trend data among eighth graders. Thirty-eight countries participated, of which 26 had been participants in TIMSS 1995. Five content areas, corresponding to the five content standards of the National Council of Teachers of Mathematics (NCTM 2000), were tested: number sense; measurement; data representation, analysis, and probability; geometry; and algebra. While the United States did show a modest improvement, the scores remained statistically below the international average for eighth grade students (TIMSS, 1999).

In an attempt to further define the differences between United States eighth grade mathematics, and that of other nations, TIMSS-2 completed an in-depth video study of classrooms within the United States, Germany, and Japan (TIMSS, 1999).

> The study sample included 231 eighth-grade mathematics classrooms: 100 in Germany, 50 in Japan, and 81 in the United States. The three samples were selected from among the schools and classrooms participating in the 1994-1995 TIMSS assessments. They were designed as a nationally representative sample of eighth-grade students in three countries (p. v).

A quick summary of TIMSS-2 findings (adapted from TIMSS, 1999, pg viii):

- The content of U.S. mathematics classes requires less high-level thought than do classes in Germany and Japan.
- U.S. Mathematics teachers' typical goal is to teach students how to do something, while Japanese teachers' goal is to help them understand mathematical concepts.
- Japanese classes share many features called for by U.S. mathematics reforms, while U.S. classes are less likely to exhibit those features.
- Although most U.S. math teachers report familiarity with reform recommendations, relatively few apply the key points in their classrooms.

Conceptual Development

According to TIMSS-2 (1999), most mathematics lessons presented in any country include a mixture of concepts, computation, and problem solving. Concepts tend to be presented two distinct ways – direct statement or derivation. More than three-fourths of German and Japanese lessons included derivation of concepts, as compared with one-fifth of United States lessons. Ten percent of German and 53% of Japanese lessons involved proofs of concepts, as compared to the United States, which involved none.

Quality of Lessons

A panel of U.S. college mathematics teachers, in order to evaluate the quality of mathematical content delivered, developed a rating scale of low-medium-high. Quality was judged according to several criteria including coherence of mathematical concepts, and the degree of deductive reasoning required. Thirty-nine percent of Japanese lessons and 28% of the

German lessons received the highest rating, compared to none of the United States lessons. Eighty-nine percent of U.S. lessons received the lowest rating, compared with 11% of Japanese lessons (TIMSS, 1999).

NCTM

In 1902, E. H. Moore, then President of the American Mathematics Society (AMS) called for an integrated approach to mathematics curriculum. There followed the first round of mathematics curriculum reform in the 20th century. The National Council of Teachers of Mathematics (NCTM) was founded in 1920 in order to preserve mathematics education in this era in which numerous calls for reform were voiced, some of which included a call to remove mathematics instruction from schools entirely. (Kilpatrick and Stanic, 1995).

During World War II, the United States became concerned with losing its technological superiority. This fear was heightened in the post-war era, which led to the creation of the "New Math" curriculum of the 1950's and 1960's (Stanic & Kilpatrick, 1992). According to Kilpatrick & Stanick (1995), the two major reform movements of the early 20th century, the "new math" and AMS's call for integrated mathematics, made little more than surface changes to mathematics education.

In the 1980's, two factors renewed interest in substantial mathematics curriculum reform. The first was the Second International Mathematics Study (Senk & Thompson, 2003), and the document "A Nation at Risk" (National Commission on Excellence in Education, 1983). Both sources highlighted concerns that the United States was losing technological superiority, just as it had been feared in the post-WWII era.

In 1989, NCTM published the "Curriculum and Evaluation Standards for School Mathematics" (NCTM 1989), which recommended a shift in focus away from rote memorization and basic skills toward conceptual understanding and reasoning. Subsequent documents from NCTM include the "Professional Standards for Teaching Mathematics" (NCTM, 1991) which focused on the teacher, the "Assessment Standards for School Mathematics" (NCTM 1995) which focused on assessment practices, and "Principles and Standards for School Mathematics" (NCTM, 2000) which can be viewed as a synthesis of the first three NCTM documents.

According to the TIMSS (1999) researchers, Japanese and German teachers come closer to implementing the NCTM standards than do U.S. teachers. Examples include such emphases as high-level mathematical thinking; focus on problem-solving; alternative solution method; and communication of findings.

One example of how such a change in emphasis (from basic skills and algorithmic thinking to reasoning and conceptual understanding) can be found in the work of Boaler (2006) in an urban school in California. The subject school, in which students worked on complex conceptual problems, was compared to two other schools which taught in a more traditional manner using demonstration and practice.

In Boaler's (2006) study, students in the subject school exhibited a higher rate of engagement, success, and love for learning. Additionally, students who experienced this reform-based approach took more and higher mathematics classes than their demographic counterparts in the other two schools in the study. This suggests that mathematics curriculum reform does in fact have a positive impact on student learning.

Boaler (2003) cautions, however, against the expectation that the positive impact of reform-based teaching may not translate into achievement on standardized tests. The very school Boaler studied was labeled an "underperforming school" (Boaler 2003) because students in the school did not perform well on state mandated testing. Boaler (2003) states:

President Bush's No Child Left Behind Act mandates the kinds of testing programs I have described in this article. Yet it is clear that some children are left behind precisely because of such testing programs, which do not measure learning… The students at Railside tell us that language and contexts - as well as the unfamiliarity of the test -- are huge barriers. For example, the students don't normally face a barrage of short questions with "fill in the bubble" answers, and they are not normally required to work without calculators. (p 502)

It is clear from Boaler's work that mathematical learning and understanding has more to do with how mathematics is taught and the learner's construction of understanding than test scores might show.

How Mathematics is taught

No sampling technique can paint a complete picture of a phenomenon, and the TIMSS study is no exception. It is also true that mathematics lessons may vary from teacher to teacher, and from day to day. Lessons early in the content will involve more instruction, where later lessons involve more practice. With these limitations in mind, TIMSS presents an analysis of a "typical" lesson within a German, Japanese, and U.S. mathematics classroom.

> <u>Germany:</u>
> The mathematics teacher sets the goal for the lesson as the acquisition of a skill or procedure for solving a mathematical problem. It is likely that the particular skill or procedure the teacher intends to teach is relatively challenging mathematically. She probably intends for the students to understand the rationale for the procedure, why it works.
> To achieve these goals, the teacher organizes the lesson so that most of the mathematical work during the lessons is done as a whole class. The teacher does not lecture much to the students; instead, she guides students through the development of the procedure by asking students to orally fill in the relevant information. This is done by presenting the students with a task such as finding the solution set to two simultaneous linear equations in two unknowns. If the problem is a relatively new one, the teacher generally works the problem at the board, eliciting ideas and procedures from the class as work on the problem progresses. If the problem is one they have already been introduced to, a student might be called to the chalkboard to work the problem. The problem might be slightly different than problems students have worked before but the method to solve the problem has been introduced previously and applied in related situations. The class is expected to monitor the student's work, to catch errors that are made, and to help the student when he or she gets stuck. The teacher keeps the student and class moving forward by asking questions about next steps and about why such steps are appropriate.
> After two or three similar problems have been worked in this way, the teacher summarizes the activity by pointing to the principle or property that guides the deployment of the procedure in these new situations. For the remaining minutes of the class period, she assigns several problems in which students practice the procedure in similar situations." (TIMSS, 1999, p. 133-134)

- <u>Japan</u>

> The goal the teacher sets for the lesson is for students to develop mathematical thinking rather than to acquire a particular mathematical procedure as in other countries. Planning for the lesson involves selecting challenging mathematical problems that might involve the development of several student-presented methods of solution or the development of a mathematical proof.
> The lesson begins with the teacher posing the selected problem. The students are then asked to work on the problem at their seats in order to generate a solution method for the problem, sometimes individually and sometimes in groups. During the seatwork period,

the teacher circulates around the class, noting the different methods that students are constructing. She then reconvenes the class and asks particular students to come to the front and share their methods. Occasionally, the teacher provides a brief lecture, pointing out a property or principle inherent in the method or explaining the advantage of particular methods that have been shared. The cycle of the teacher presenting a problem, students working on the problem at their seats, and students sharing their solutions with the class, is repeated several times during lesson.

Much mathematical work in the lesson gets done during seatwork. But students are given support and direction through the class discussion of the problem when it is posed, through the summary explanations by the teacher after methods have been presented, through comments by the teacher that connect the current task with what students have studied in previous lessons or earlier in the same lesson, and through the availability of a variety of mathematical materials and tools. (TIMSS, 1999, p.134)

- United States

The mathematics teacher sets the goal for the lesson as the acquisition of a skill or procedure for solving a mathematical problem. The goal probably specifies a particular procedure that all students are to acquire rather than generating alternative solution methods and the emphasis will be placed on acquiring the mechanics of the procedure rather than learning why the procedure works. Compared to Germany and Japan, the procedure to be learned is at a relatively simple mathematical level.

The lesson typically includes the teacher asking students about their homework. The teacher works one or two problems with which students have had difficulty and the homework is collected. The teacher then presents one or more definitions or properties or principles, often in the form of procedural rules, that will guide the students' application of the procedures for the next set of problems. This might be in the form of a demonstration of a new procedure or a reminder of how a procedure is used in the situations presented in this lesson. Several examples are then worked together as a class, with the teacher using the chalkboard or the overhead projector. The problems are probably drawn from the textbook or a teacher-made worksheet, and few materials or tools are used other than paper and pencil. The teacher guides the students through the procedure by asking short-answer questions of the students, such as what is the partial result for this step in the procedure, or what operation is called for in the next step.

The teacher assigns a number of problems of a similar kind as homework. The students work on the problems until the end of the period. The problems function as practice exercises for the procedures demonstrated earlier." (TIMSS, 1999, p. 134-135)

Analysis of German, United States, and Japanese Teaching Methods

Comparison summary (adapted from TIMSS, 1999, pg 136)

Japanese lessons (eighth grade)

- Teacher poses a complex, thought-provoking problem.
- Students struggle with the problem.

- Various students present ideas or solutions to the class.
- The teacher summarizes the class' conclusions.
- Students practice similar problems.

U.S. and German lessons:

- Teacher instructs students in a concept of skill.
- Teacher solves example problems with the class.
- Students practice on their own while the teacher assists individual students.

In terms of the five goals set by the NCTM, Japanese lessons seem more likely to promote learning with understanding (goal #1) through the use of high-level thinking skills and problem solving within a group-collaboration setting (goal #5). Japanese lessons also seem to meet the goal of diversity and flexibility (goal #3), since multiple solutions are accepted. Japanese teachers seem to promote reflection (goal #4) through their whole-class summary of the day's work.

Examination of Japanese teaching methods presents a unique opportunity to clarify what is lacking in current U.S. eighth grade classrooms. According to NCTM's (2000) reform statements and goals, U.S. eighth graders need to work on complex thought-provoking problems, and should be allowed to derive solutions in multiple ways. U.S. eighth grade teachers need to provide learning opportunities that are conceptually rich within a social context, which allow students to construct their own understandings. These statements are consistent with the call for real-life problem solving (Brown, Collins & Duguid, 1989), and accommodations for different learning styles (Gardner, 1993). A possible method of advancing the NCTM (2000) reform agenda of complex, conceptually rich problem solving within a social context can be found within the concept of Project Based Learning.

Project Based Learning

Project Based Learning (PBL) may have its origins nearly 100 years ago with educational pioneers such as John Dewey, who advocated educational practices which focused on experiential, hands-on, student-directed learning (Markham et al., 2000). The modern incarnation of PBL may be said to originate in the 1960's at McMaster University, which used a PBL approach in its pre-med program (Barrows, 1992) because it placed students in authentic experiences instead of having them just read about them.

What is PBL?

Project Based Learning is best differentiated from other learner-centered teaching processes by the fact that PBL places a "project" at the central focus. A project can best be described as an authentic, ill-structured problem (Savery & Duffy, 1995) which requires the creation of an artifact of learning (Blumenfeld et al., 1991) by way of a solution.

Authentic problems are problems which are anchored in real-life, and are the sorts of problems a student is likely to encounter in their daily life (CGTV, 1992). The problems are said to be ill-structured because students have insufficient information to arrive at a solution, and are therefore required to identify what they need to learn to solve the problem (Nelson, 1999). In order to be a project, students must create an artifact of learning which should represent the transformation and construction of new knowledge or skills (Bereiter & Scardamalia, 1999).

Features of PBL

Krajcik, Blumenfeld, Marx, & Soloway (1994) specify that problem solving with PBL has five key features: an authentic question or problem which organizes and drives activities; student-generated products or artifacts which address the problem; investigation which requires research over extended time; collaboration with peers, teachers, and others in a community of inquiry; and the use of cognitive technology tools for study and communication.

The driving question, according to Krajcik et al. (1994), should be: feasible (students will be able to answer the question in some manner); worthwhile (the content should relate to what is done in real-life); contextualized (holds as much fidelity to the real-world as possible); and meaningful (interesting and exciting to students). Additionally, in this study I have added to the definition of driving question an additional component as described by the Buck Institute for Education (BIE). According to BIE, a driving question can be designed in such a way that it is tied to the content standards of the curriculum. In this way, the driving question itself creates a need to know the material (Markham et al., 2000), thus forming a "standards-based driving question".

In a PBL styled classroom, students should be creating artifacts of learning with which to form multiple representations of understanding, as expected by constructivist theory (Krajcik et al, 1994). In this study, students will take advantage of a particular benefit of the creation of artifacts. With concrete artifacts, Krajcik et al. (1994) suggests that “they can be displayed and critiqued by others…as a result; learners can reflect on and revise their artifacts, thereby enriching their knowledge (p. 488).” In this study, students conduct such “peer reviews” of the artifacts they create.

Within a PBL classroom, students and others have the opportunity to work together over time to investigate an engaging problem. Students can discuss possible solutions, make and test conjectures, and share the results of their tests with each other. In this study, students form a community of learners as they study three scenarios over time. Some of these communities are small (2-5 students), or large (whole class) depending on the scenario being studied.

Krajcik and his colleagues’ (1994) definition of PBL requires the use of cognitive technology tools for study and communication. They state that using technology in PBL “makes the environment more authentic to students, because the computer provides access to data and information, expands interaction and collaboration with others…and emulates the tools experts use to produce artifacts” (p. 488-9). In this study, students used STELLA™ simulations, spreadsheets, SimCity™, and HyperStudio™ in addition to the internet as their cognitive technology tools.

PBL in Math

Boaler (1998) describes a longitudinal (3-year) study which compared two British high schools. Both schools were carefully selected to have populations as similar in demographics and backgrounds as possible. One of the two schools in the study employed traditional teaching methods such as didactic (teacher-centered) whole-class instruction, reliance on textbooks, tracking, and frequent testing. The other school used a PBL approach, where students worked in groups to solve open ended problems, and infrequently used testing and textbooks.

Boaler’s interviews with students showed that students in the traditional high school considered their mathematics work to be "boring and tedious…the students regard mathematics as “a rule-bound subject and they thought that mathematical success rested on being able to remember and use rules." Whereas, in the PBL high school, students felt mathematics was a "dynamic, flexible subject that involved exploration and thought." (Boaler, 1998, p. 63).

On nationally administered tests, students at the project-based school were found to perform at least as well or better than the traditional school students.   On rote knowledge, PBL students did as well, on problem-solving, PBL students outperformed the traditional students.

Boaler (2006) also conducted a similar study in California, sometimes referred to as the “Railside” study, with similar settings.   Three schools were studied, two using more traditional approaches, one using more reform-based approaches.   Her findings were consistent with that of the British study, with the notable exception that the “Railside” school did not do well on NCLB assessments as noted earlier in this chapter.

Boaler’s work is the best research we have to date about the effect of project-based environments on students’ mathematical learning and attitudes. In this era of high-stakes testing under NCLB, teachers and administrators may know that PBL is a good strategy for learning for their students but have become fearful of using this strategy because of the serious consequences for their school if their students do not perform well on the yearly assessments. Due to the lack of research that directly answers the question of how students in a PBL classroom fare on standardized assessments, good teaching strategies are being dropped in favor of teaching to the test. This study adds to Boaler’s work by examining student learning of mathematical concepts that are listed in the NCTM Standards. Hopefully this provide the next logical step in the research that demonstrates high quality mathematics learning in PBL environments.

Dynamic Computer Modeling

Computer-based dynamic models have a positive impact on the learner in four distinct ways: The ways in which new knowledge is represented, exploring new knowledge, generating and testing hypotheses, and application of new knowledge

Representing New Knowledge

Marzano, Gaddy and Dean (2000) note that the predominant means of presenting new knowledge to students, whether in classroom interactions or in textbooks, is linguistic.   In his meta-analysis of research into instruction, Marzano (1998) found that when students create and use non-linguistic representations of new concepts, this increases their achievement. Although teachers and textbooks may incorporate as many visuals into their instruction as possible, computer simulations based on visual representations seem to be ideal for providing such a non-linguistic medium of learning.

Exploring New Knowledge

Manipulatives are concrete representations of symbolic concepts with which students directly interact with while learning new concepts. An example of a simple manipulative would be a simple counter, which can be as simple as a poker chip, but which can become a tangible representation of the abstract concept of a number. Students can make use of these representations when learning about concepts such as whole number addition by noting, for example, that 2 + 3 is the same as placing two chips next to thee other chips, which gives a total of five.

With computer-based simulations, the concept of a manipulative is taken to a higher level, as students are able to concretely see the interactions of higher-level concepts in much the same way as counting poker chips leads to an understanding of addition. As Clements & McMillen (1996) state:

Such computer links can help students connect many types of representations, such as pictures, tables, graphs, and equations. For example, many programs allow students to see immediately the changes in a graph as they change data in a table. These links can also be dynamic. Students might stretch a computer geoboard's rectangle and see the measures of the sides, perimeter, and area change with their actions.

Generating and Testing Hypotheses

Clement & Mcmillen (1996) caution, however, that while electronic manipulatives are powerful tools, they derive their greatest power when students are guided in their use, and reflect on the effects their manipulations had. One way to accomplish this guided reflection is in the practice of generating conjectures (or hypotheses), and testing those conjectures on the simulation. This is an important theme in grades 6-8, as described by NCTM (2000):

In the middle-grades mathematics classroom, young adolescents should regularly engage in thoughtful activity tied to their emerging capabilities of finding and imposing structure, conjecturing and verifying, thinking hypothetically, comprehending cause and effect, and abstracting and generalizing. (p. 211)

Application of New Knowledge

Marzano (1998) indicates that students learn most effectively when they are first presented with new knowledge or concepts, and then are given an opportunity to apply that knowledge to a new situation. Computer simulations are ideal in this context, as they provide a workspace upon which students may safely experiment with their new knowledge.

As described by TIMSS (1999), a typical U.S. eighth grade teacher trying to provide students with an opportunity to learn quality mathematics as described by NCTM (2000) may find the task complicated by the fact students have had seven years of mathematics taught in a typically American manner. While school-wide reform is beyond the scope of this study, the classroom tool of dynamic modeling may afford a method of providing the kind of quality mathematics instruction described by NCTM (2000) in the short term in individual classrooms.

Computer simulations and dynamic modeling share many similarities. Both are powerful tools for teaching students due to the mental dexterity required to use them (Rumelhart & Norman, 1981). The term "dynamic model" refers to a model that is in some way sensitive or responsive to the passage of time. This study makes no distinction between a dynamic model and a simulation, as only those simulations that are time-sensitive will be considered. For the sake of this study, simulation will be defined as:

> A non-linear and manipulable model, representing a real or imagined phenomenon, that has the ability to present, either visually or textually, the current state of the model (Thomas & Hooper, 1991). In addition, the simulation allows the user(s) to track his/her progress within the model (Barab, Bowdish, & Lawless, 1997; Williams & Dodge, 1993) and provides feedback in realistic forms (Alessi, 1991). (Hargrave & Kenton, 2000, p.48)

Simulations provide students with the opportunity to directly interact with a model of reality. The model is a simplified version of reality or in some way represents situations that are too difficult, too dangerous, too large, or too small to reproduce in a lab setting or are impossible to measure (Kornblugh & Little, 1976). Forrester (1968) claimed that creating and running such models helps foster deep understanding of complex systems. The American Association for the

Advancement of Science Project 2061 (1993) promotes the use of mathematical models to better enable students to form a scientific understanding of their universe.

Simulations in Science

Computers have been used in various disciplines within science, especially for providing students with a constructivist learning environments, and primarily for the re-conceptualization of misconceptions. White (1993) suggested that students could use simulations to identify and revise their own misconceptions about Newtonian physics. Byrna (1991) and Gorsky & Finegold (1992) reported finding students working with simulations in the midst of cognitive dissonance, and proposed using simulations as a method for teachers to identify students with misconceptions.

Examples of phenomena that are too difficult, dangerous, or hard to measure within a normal lab setting include Andre & Haselhuhn's (1995) description of a project where students are given a computer simulation of a rocket in outer space. Students experiment with concepts such as momentum, force, and velocity in a weightless environment. Kenton (1997) designed a simulation of an electronics workbench where students connect virtual bulbs and wires to a power source to investigate electric circuitry.

Modeling complex phenomena can provide scaffolding for students as they study such concepts as ecology, (Silvert, 1993) and social and population dynamics (Mandinach, 1988; iseeSystems, 1992).

Modeling in Mathematics

Wallace (1992) calls for a move away from textbook style problems, toward more real-world problem solving situations. Wallace notes that real-world problems come with irrelevant as well as relevant information. The art of problem solving does not involve the use of memorized algorithms; instead the solver must assess the problem and formulate a strategy based on the guidelines and given available and on the obstacles and the possibilities for solution that are at hand.

Wallace proposes the creation of situations (simulations/models) that are representative of the kinds of problem students will see in real life – situations "in which they must first define the question and then decide what type of data to collect, how to collect and organize the data, and how to analyze the results to reach a solution." (Wallace, 1992, pg 82)

Wallace summarizes the kinds of situations best suited to simulation as those which are "less than clearly defined, open-ended, and require skills from several areas of secondary mathematics…students [should be] required to define the problem, collect data, analyze and interpret those data, and evaluate the results." (Wallace, 1992, Pg 87). Wallace also supports the idea of students forming and testing conjectures. "They can change the conditions, make and then test intuitive guesses, and learn how to use the technology that is available to them." (Wallace, 1992, pg 87)

STELLA

STELLA™ (Structural Thinking and Experiential Learning Laboratory with Animation) is an object-oriented programming environment published by iseeSystems (formerly High Performance Systems). STELLA™ allows the creation of complex simulations using only four basic building blocks: the stock (which serves as a reservoir or value holder), the flow (allows information or values to enter or exit a stock), the converter (which regulates the flow), and the connector (which connects converters to the flows they control) (See Figure 1 in Chapter 1).

According to Eskrootchi (2001), dynamic modeling simulations take one of two forms. The first of which requires students to build their own simulation which models a given scientific or social phenomenon. The second requires students to manipulate the parameters of a given simulation and examine the subsequent effects on the entire simulated system.

Mandinach (1988) studied a high school in Vermont, which had incorporated STELLA™ into their physical science, biology, and chemistry classes. The results of Mandinach's (1988) study support the idea that the manipulation of parameters in teacher-built models promotes scientific inquiry skills, acquisition of new knowledge, and problem-solving skills. My study focuses on this type of simulation – students manipulating parameters and evaluating results.

Other modeling software

A search for recent literature involving simulations, as defined earlier, mathematics, and middle school students reveals that surprisingly few studies have been conducted, which speaks to the need for studies like this. There were, however, numerous instances of modeling and simulations in science classrooms at the secondary level, as well as modeling and simulation at higher levels of math. A representative selection follows.

Gina Cherry (2003) studied fifth graders interactions with two versions of EcoWorlds™ software, which models a virtual ecosystems impact on various animal species. She found that the version of EcoWorlds which incorporated background information promoted more learning than the open-ended version.

Technology based simulations, when used with high-achieving students in high school science classes, seem to encourage more complex reasoning, deeper conceptual development. And help students address their own misconceptions about scientific concepts (Hurwitz, 2007; Zimmerman, 2002).

Simulations seem to benefit low-achieving students and students of low socioeconomic status as well. Computer simulations seem to be a strong motivator for low-achievers, and promote collaboration and productivity, higher order questioning skills, problem solving and reasoning among economically disadvantaged students (Hakerem, 1996; Chiu, 1996).

STELLA in the classroom

While there are no published studies involving the use of STELLA in the mathematics classroom at the middle school level within the past ten years, it is worth noting that the Maryland Virtual High School, and its parent school Montgomery Blair High School have integrated STELLA modeling into nearly every area of their curriculum. Additionally, in Carlisle Public Schools (MA) Rob Quaden, Alan Ticotsky, and Debra Lyneis use STELLA as part of their high school math and science curriculum. Finally, it is important to mention Diana Fisher of Franklin High School, Oregon, as one of the more prolific authors of STELLA-based interdisciplinary curricula.

It is clear there is much interest on the part of practitioners in the use of STELLA as an instructional tool. There is a paucity of scholarly study of the integrated curricular use of STELLA™ at the middle levels. This suggests that it is appropriate to study STELLA™ in the middle school mathematics classroom, especially in a Project-Based Learning environment.

Theoretical Underpinnings

Constructivism

Constructivism emphasizes the importance of meaningful, authentic activities that help learners construct understandings and develop skills relevant to solving problems (Wilson, 1996). Adding the term "constructivist" to learning environments implies the creation of a time and place, as well as a process of teaching that provides learners the opportunity to build understanding. According to Staver (2000), a constructivist learning environment would require students to explain their understanding and reasoning through viability, or "fit." Conceptual models would be considered viable if they are coherent within the context they were created.

Perkins (1991) suggests that learning environments include the following components or functions:

- Information banks, which may include such items as textbooks, teachers, encyclopedias, videotapes, CD-ROMs, etc.
- Symbol Pads, which are surfaces for the construction and manipulation of language and meaning. These may include student journals, word processors, drawing programs, etc.
- Phenomenaria, which Perkins defines as "areas" for presenting, observing, and manipulating phenomena. These may include computer simulations, microworlds, aquaria, etc.
- Construction Kits, which are collections of components for assembly and manipulation. These are different from phenomenaria in that they have no actual correlation to the real world. These may include hypertext authoring tools, math manipulatives, etc.
- Task managers, which are those components, which supervise, control, guide, give feedback, and direction. This can be a teacher, group members, peers, grading systems, classroom rules, etc.

Contrasting constructivist environments with more traditional learning environments, Perkins goes on to say that in a traditional environment much of the information told to students (information banks instead of phenomenaria), and much of their learning managed for them.

Constructivist learning environments, however, give students the responsibility to manage their own learning, construct their own understanding, and the role of the teacher becomes that of facilitator instead of leader (Perkins 1991).

Honebein (1996) describes a constructivist learning environment as one in which students take primary responsibility for learning, placing the teacher in the role of facilitator. Students must also engage in activities that enable them to investigate alternative solutions to problems, and to test these solutions for best fit. Additionally, the context being examined must be relevant, and realistic, and must be a social experience.

von Glasersfeld (1995, p. 51) holds that:

- Knowledge is not passively received either through the senses or by way of communication; knowledge is actively built up by the cognizing subject.
- The function of cognition is adaptive, in the biological sense of the term, tending towards fit or viability; cognition serves the subject's organization of the experiential world, not the discovery of an objective ontological reality.

Constructivism, therefore, is actually a way of "coming to know" rather than a theory of knowing. Knowledge is built, actively, by the learner through experience. For each individual, that knowing will be equally individual. We cannot compare what we know with reality; we have no way to triangulate with others based on our experiences (Von Glasersfeld, 1995).

Merrill (1991) suggests there are six basic assumptions for educators working within constructivist learning theories:

- knowledge is constructed by the learner;
- learning is a personal interpretation of experience;
- learning is active;
- learning is collaborative;
- learning is situated in real world contexts; and
- assessment of learning is integrated within the learning context itself.

These assumptions closely parallel the five learning goals of NCTM (NCTM 2000), and are consistent with constructivist learning environments as described by Perkins (1991) and Honebein (1996).

Computers are unique tools for assisting learners as they construct their understanding of a situation. The learners can investigate their understanding by actually "teaching" the computer

(Taylor, 1980). The computer can provide a "microworld" for learners to experiment with (Papert, 1980). White's (1993) ThinkerTools provides a model of Newtonian physics, allowing students to model and observe simulations of real-world phenomena in more detail than would be possible in a laboratory setting. Other software environments, such as dynamic system modeling, may provide tools for modeling other real-world phenomena.

It is the nature of knowledge within the constructivist epistemology that may suggest the problem within mathematics instruction – that learning is not a transfer of knowledge from teacher to student, from expert to novice. Rather, learning is a "process of building up structures of experience" (Jonassen and Duffy, 1992, p. 26). Learners bring with them their past experiences and interactions with the world. These experiences and interactions influence the way the learner incorporates new understanding (Jonassen and Duffy, 1992).

Situated Cognition

Brown, Collins, and Duguid (1989) describe situated cognition as a learning theory in which a learner learns new knowledge in a context that, as closely as possible, approximates the environment in which that new knowledge will be applied. Brown et al. (1989) indicate a primary concern about traditional schooling is that it tends to be the transfer of abstract, decontextualized formal concepts. From their perspective, schools seem to value the memorization of facts over actively building understanding.

Whitehead (1929) distinguishes between the acquisition of facts and the development of useful knowledge – a tool may be quite useful, but without the knowledge of when and how to use it, remains unused.

Situating the learning within the culture, or society, for which the information is useful can help to alleviate this "uselessness" phenomenon. Brown et al. (1989) describe the different uses for a tool, depending on the community of users. A cabinetmaker may use a chisel differently from a carpenter, just as a physicist may use a formula differently than a mathematician.

It is not my intent to suggest that all students studying mathematics must become mathematicians to find relevance in the formulae they learn. Rather, the relevance and use of a tool may be demonstrated for the learner by a teacher who can act as practitioner, providing examples for the students of actual use of the knowledge.

Perkins (1992) expresses his own dissatisfaction with education, as learners are given facts to learn without context. "Students have knowledge that they remember when directly quizzed, but do not use otherwise." (Perkins, 1992, p. 22) Perkins agrees that the goals of education should be retention, understanding, and active use of knowledge (Perkins, 1992), but that the knowledge should be "generative knowledge – knowledge that does not just sit there but functions richly in people's daily lives to help them understand and deal with the world" (Perkins, 1992, p. 5).

Lave (1997) suggests that learning is connected with the environment, including other people, and is stretched across individuals, context, activity, culture, material objects, and even time. This "stretching across," in this context, implies a that the learner is not isolated, but rather is influenced by the environment. Learners' understanding is also stretched across the multiple dimensions, and is evolutionary in the sense that it will change across time and environmental differences.

In the middle school classroom, Lave (1997) indicates that learning and knowing can be observed when students are interacting with each other during some activity with someone or with something in their environment. Observations of learning and knowing will be tied to the learning situation in terms of who is learning (the culture and the individual), where they are learning (the context), what they are learning (the activity), what they use to learn (the materials), and how long they learn (time).

In my study, students interact with me, each other, and the computer simulations as their environment of learning. My observations of their learning are situated in the context of the students (who) in the classroom (where) as they work with the three simulation scenarios (the activity and materials) over a series of three approximately month-long projects (time).

CHAPTER 3 - Method

Goal of the Study

The goal of this study is to explore the use of interdisciplinary PBL projects for teaching mathematical concepts according to NCTM (2000) goals for mathematics instruction. These projects involved students in using the STELLA™ and other dynamic modeling software. My initial guiding question was: What are the teaching issues and evidence of student learning of mathematical concepts over a series of three interdisciplinary PBL projects involving STELLA™ modeling software which are designed to engage students, integrate technology, and provide a context for learning mathematics based on the 5 NCTM (2000) goals?

The data gathered in this study can be characterized as belonging to two variable clusters: teaching, and learning. Two sub-questions were developed relating to the two variable clusters:

What are the issues related to teaching mathematics concepts in a technology-rich, interdisciplinary PBL project which follows the 5 NCTM (2000) goals?

What are the issues related to learning mathematics concepts in a technology-rich, interdisciplinary PBL project?

To achieve this goal, I employed qualitative research and analysis techniques to provide a rich source of evidence. This chapter includes descriptions of research design, research site, participants, setting, data collection and analysis.

Research Design

Yin (1994) concludes that the methodology used in a research study tends to be driven by the research question and the phenomenon being studied. This study took place within the culture of learners and learning groups of a middle school classroom as students built dynamic models of real-world phenomena. I sought to answer the question: "What are the teaching issues and evidence of student learning of mathematical concepts over a series of three interdisciplinary PBL projects involving STELLA™ modeling software which are designed to engage students, integrate technology, and provide a context for learning mathematics based on the 5 NCTM (2000) goals?" Merriam (1988) describes research conducted in such a subjective and interactive context as "naturalistic" in nature:

> Research is exploratory, inductive, and emphasizes process rather than ends. In this paradigm, there are no predetermined hypotheses, no treatments, and no restrictions on the end product. One does not manipulate variables or administer a treatment. What one does is observe, intuit, sense what is occurring in a natural setting (p. 17)

A naturalistic study implies the researcher believes the world to be constructed of "multiple realities that can be studied only holistically" (Lincoln & Guba, 1985, p. 37). Such a researcher would focus on the experiences which occur in context, since the study is tied to a time and place (Lincoln & Guba, 1985). My rationale for using a naturalistic case study approach is that it enabled me to study the phenomenon within its natural context (Lincoln & Guba, 1985). Patton (1987) agrees that a naturalistic approach is appropriate for studies situated in classroom contexts.

The data are gathered with the goal of providing a "thick description" (Geertz, 1973) of the setting and the interactions of the subjects within that setting. This study provides a rich, thick description of what took place within the classroom as students engaged in a series of 3 interdisciplinary, PBL projects that modeled real-world processes involving mathematics, and interpretations of the development of students' understanding of math concepts during the PBL experience.

A naturalistic researcher is aware of the importance of interactions between themselves and the subjects being studied. In this study, I assumed the role of participant observer, as this study took place in my classroom. Multiple sources of evidence were collected. Daily field notes were written down and dated for later analysis. Observational data were collected by videotape[1], analyzed and interpreted after the fact. For the sake of triangulation, videotaped observations were supplemented with interviews, and document analysis. Through this process, as described by Viner, "the investigator tries to find ways to explore and describe the everyday experiences of a group of people through the use of observations, interviews, and artifacts" (2003).

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[1] During this study, a fellow researcher was present doing a parallel study which involved videotaping the class. I used his videotapes as one data source for my study (See "Other research on this same classroom" at the end of this chapter).

Access

Permissions to conduct this study were obtained from the participating school district, building administration, and Kansas State University. Parents and students selected to participate in this study were asked to complete a Human Subjects Consent Release, which described the goals, methods of analysis, risks and benefits of the study. All participants were informed that their confidentiality would be maintained. Names of participants were removed and replaced by coded letters and numbers. All participants were informed that they could leave the study at any time, and that participation did not affect their classroom grade. The parent of one student who initially agreed to participate in the study chose to opt out during the study. This student was transferred to another class which was not participating in the study.

Research Site

This investigation was conducted in a middle school located in a Midwestern city, with a population of approximately 20,000 according to the 2000 census (Census of Population and Housing, 2000). Students participating in this study were eighth-grade students selected from students taught by an integrated curricular team composed of four core teachers with classes of approximately 24 students each, for a total of approximately 96 students. The team consisted of four content teachers (math, science, English, social studies), one special education teacher (students with special needs were enrolled in various classes), and numerous paraprofessional special education teachers who assist the special education teacher. This team is considered an integrated curricular team, as teachers are encouraged to create activities that integrate the other three content areas in aspects of their particular content area. I taught four classes: two sections of pre-algebra, and two sections of algebra. The focus of this study was on the two algebra classes.

Participants

The school's enrollment during the study was 822 students, approximately 50% female and 50% male. The demographics of the student population consisted of 55% white, 32% black, 8% Hispanic, 4% Pacific Islander and 1% Native American. Economically disadvantaged students comprised approximately 53% of the population.

The study site employed a middle school philosophy of integrated core-curricular classes: English, Math, Science and Social Studies. Approximately 90 students were divided into four groups of approximately 25 students each, designated as Class A, Class B, Class C, and Class D. The core-class portion of the school day was divided into four periods. Four groups of students (designated Classes A, B, C, and D) met with each of the content areas for approximately one hour: Class A – 9:05 a.m., Class B – 10:05 a.m., Class C – 11:05a.m. and Class D – 12:35 p.m. Every six weeks the classes rotated by one hour (Class A would meet when Class B normally met, Class B when Class C normally met, etc.).

All four classes (approximately 90 students) were given the opportunity to participate in the study by signing and returning human subjects permissions forms. Roughly 50% of students returned the forms with the required signatures, and were allowed to participate in the study. Special Education students were purposely excluded due to concerns about Individual Education Plans (IEPs). Two classes (A and D) were selected to be the "Project Classes." Students who had chosen to participate by returning signed permission forms were assigned to those two classes. Over time, attrition and student mobility resulted in only one class of 22 students who had agreed to participate in the final two projects. The demographics of the resultant group (8 male, 14 female) were 36% white, 27% black, 13% Hispanic, 13% Multiracial, and 9% Pacific Islander.

I was the researcher and the mathematics instructor for all participating students. I taught with three other instructors on the interdisciplinary team. The team collaborated daily on lesson plans, activities, and integrated thematic units as is part of an interdisciplinary teaming approach. Previously, I had been a high school math, science, and technology instructor, and a Y2K programmer. My background includes a Bachelors degree in Computer Science and a Masters in Secondary Education specializing in Educational Computing, Design, and Telecommunications.

The Researcher's Philosophy

I believe in providing students with learning environments which are engaging and authentic. This generation of students is steeped in technology, and bombarded by media. Traditional schooling tends to be neither of those. While I don't believe schools should become commercialized, we educators need to acknowledge that our lessons must compete for students' attention against MTV, the Internet, and modern telephony. Computers are cool, multimedia is cool, doing anything new and different is cool, and this is the age when cool is everything. I have to have a teaching philosophy which will engage this digital generation. As a result, I am willing to tolerate a little noise and a little chaos. My goal is that they should stop believing that learning math must be a drudge, and can be as exciting and engaging as any computer game.

Setting

Throughout the 2001-02 school year, students involved in this study built HyperStudio™ stacks and interacted with dynamic modeling software. The interactions with dynamic modeling software increased in complexity and scope over the series of projects. Students' conceptualization and understanding of the factors involved in building dynamic models were scaffolded over time as they participated in this sequence of study, with particular emphasis on cross-curricular integration. Within this cross-curricular, technology- and concept-rich project based learning environment, Algebra I students created three dynamic models, or "projects."

The dynamic modeling software used for this study is called STELLA™, and is produced by iseeSystems (formerly High Performance Systems, Inc). This software allows students to create and manipulate models of varying levels of complexity, and to generate data in the form of graphs or data tables for easy comparison with actual data.

Brief Descriptions of the Projects

The following are a brief overview and description of the 3 interdisciplinary PBL projects the students engaged in during the school year. A more detailed description, including a listing of the expected mathematics and technology concepts covered by the projects, appears in Chapter 4.

Project #1: The Mysteries of Easter Island.

The first project asked students to interpret the results of a computer simulation run by STELLA™ dynamic modeling software. Students took on the role of a "World Heath Organization" representative sent back in time to help the residents of Easter Island (Rapa Nui) avoid their population meltdown. Through manipulation of variables such as birth rates, resource allocation, and tree replanting, students studied concepts of graphing variables over time, and the cause-and-effect relationships between the variables they manipulated. Students then created HyperStudio™ stacks to explain their conjectures and conclusions. Peers and teachers from other content area and grade level classrooms evaluated student work, and students used this feedback to refine their projects. The timeline for this project was approximately 3 to 4 weeks. Students worked on the projects Mondays through Thursdays.

Project #2: The Dam Project.

The second project was called "The Dam Project." Students were required to role-play as Civil Engineers, Conservationists, Recreation vendors, and Native Americans. Each perspective had an interest in how the water behind a simulated dam was utilized. By design, these interests were in direct conflict with each other. From their assigned perspectives (Engineer, Conservationist, Recreationist, Native American), students developed management plans for a simulated reservoir and dam. STELLA™ was used to test their management plans, and to explore the mathematical concepts of formulating conjectures, analyzing decisions and the impact of changing variables, and providing arguments based on data generated by the STELLA™ simulation. The students presented their arguments and data in the form of a HyperStudio™ stack, which was evaluated and critiqued by an authentic audience of 7th graders from another school. This phase of the project took six weeks. Students initially worked Monday through Thursday, and Fridays were added late in the project.

Project #3: The City of the Future

The third and final project required students to create a new model that is as "polished" as possible. Students incorporated knowledge gained in the first two projects to enhance their performance on the final project. Given a real-world situation, such as balancing the electricity needs of a community powered entirely by renewable resources, students created a dynamic model of that situation using the skills they learned in project one. Students compared the output of their model with the real-world data, and refined or revised their model using skills from project two.

In project three, students investigated concepts of linear and nonlinear systems (e.g., power consumption as a function of the daily temperature, power created as a function of available wind/water/sunlight). Students relied heavily on their understanding of rates, ratios, probability, statistics, and variables from the first two projects to help them create, test, and refine their model. Communication and justification skills from the third project were used, as the final product was another HyperStudio™ stack, designed to highlight the benefits of the student's city. The timeline for this phase of the project was approximately four weeks. Students worked Monday through Friday.

Available Resources

For projects 1 and 2, the students worked on 11 networked 486 PC computers located in the math classroom. For the final project, a new computer lab was available such that each student had access to a Pentium-class, networked computer. The students also had access to a photographic scanner, a digital still camera, and a VHS video camera for the incorporation of images into the students' designs. In addition, participants had access to the Internet, science texts, and library media such as books, journals, and magazines.

Data Collection

This study seeks to answer the general question: What are the teaching issues and evidence of student learning of mathematical concepts over a series of three interdisciplinary PBL projects involving STELLA™ modeling software which are designed to engage students, integrate technology, and provide a context for learning mathematics based on the 5 NCTM (2000) goals?

Barab, Hay, and Yamagata-Lynch (2001) state that conceptual knowledge or "knowing about" is a dynamic activity situated within the interactions between collaborating individuals and their environment. It is therefore necessary to collect data situated within the social interactions of subjects. Lincoln and Guba (1985) suggest that the participant observer is best able to provide rich insights into the dynamics and interactions of the participants in a learning situation. I was the researcher, but I was also the teacher and disciplinarian for the participants in this study, so it was necessary to utilize videotape as a source of observation data. Jordan and

Henderson (1995) state that videotaping also provides the ability to replay events repeatedly to impartial viewers for analysis.

Three types of data were collected for purposes of triangulation, which would increase trustworthiness of interpretation: 1) observations captured through field notes and videotape, 2) student interviews, 3) artifacts of teaching and learning, which include my lesson plans and notes, and student-constructed artifacts, and 4) student-peer reviews of each project.

Two video cameras were situated in the classroom, one directed at the computers, the other at the rest of the room. These cameras recorded every day the projects were worked on. Project one took approximately six weeks for a total of 96 hours of tape (2 cameras x 24 days x 2 classes). Project two took approximately 6 weeks as well, but one class was dropped while one extra work day per week was added, for a total of 60 hours of tape (2 cameras x 30 days). Project three took four weeks, and since it was in a different classroom we were only able to bring one camera, for a total of 20 hours of tape.

Student interviews were conducted during class time with randomly selected small groups of students (usually five at a time) meeting with Viner in another classroom to be videotaped. This would occur during project work time. The interviews were repeated until all students had been interviewed. This meant three or four sessions of interviews, at approximately fifteen minutes each, at the culmination of each of the three projects (a total of three hours of taped interviews).

Data were evaluated within the context of four main areas suggested by Roth (1996): a) to document practices (problem solving, inquiry) and resources (concepts, tools); b) to capture discussions among students and between students and teachers; c) to document student progress on their projects, and d) to trace the same students, artifacts, actions, and practices over time.

Two clusters of variables suggest themselves based on the initial question of: "What evidence is there of students' learning of mathematical concepts over a series of three interdisciplinary PBL projects involving STELLA™ modeling software which are designed to engage students, integrate technology, and to provide a context for learning mathematics based on the 5 NCTM (2000) recommendations (See Table 3). These clusters are "Teaching" compared to "Learning."

Table 3. Variable clusters - Teaching compared to Learning

Teaching	Learning
Observational data of teaching Interviews with me (conducted by Viner, see end of this chapter) focused on teaching. Interviews with students focused on teaching Artifacts of teaching (lessons, notes, guidelines, forms, etc.)	Observational data of learning Interviews with me (conducted by Viner, see end of this chapter) focused on learning Interviews with students focused on learning Artifacts of learning (the project stacks)

The following Data Planning Matrix was adopted from Viner (2003) and Lecompte and Preissle (1993) for the purpose of providing a qualitative framework for understanding the data collection procedures.

Table 4. Data Planning Matrix (Lecompte and Preissle 1993, p. 52-3)

What do I need to know?	Why do I need to know this?	What kinds of data will answer the questions?	Where can I find the data?	Who do I contact for access?	Timeline for acquisition.
How the 3 PBL projects were conducted with the students.	To understand how the teaching of math concepts is impacted by computer modeling & PBL.	Observation, interviews, student artifacts	Examination of student artifacts, observations across all 3 projects, videotape and field notes	Middle School and individual teachers	September 2001 through May 2002
What evidence is there, through the course of 3 projects that students have understood the expected math concepts?	To understand how the learning of math concepts is impacted through interaction with dynamic models and creation of artifacts of learning.	Observation, interviews, student artifacts	Examination of student artifacts, observations across all 3 projects, videotape and field notes.	Middle School and individual teachers	September 2001 through May 2002

Data Analysis

Cresswell (1998) and Merriam (1998) describe a general qualitative analysis process of constant comparative analysis. Glaser & Strauss (1967) describe constant comparison as a comparison of data collected in the field, and a further cross-referencing of that data to create categories. The three classroom projects analyzed in this study were compared to one another across categories and over time to describe the participants' learning process. As data were collected, they were examined for themes and categories, which were refined and revised over time as new categories and themes emerged from the data.

My initial guiding question was: What are the teaching issues and evidence of student learning of mathematical concepts over a series of three interdisciplinary PBL projects involving STELLA™ modeling software which are designed to engage students, integrate technology, and provide a context for learning mathematics based on the 5 NCTM (2000) goals? Based on this question, data were categorized two ways: 1) Teaching – what happened during the projects; 2) Learning – what evidence was found for learning of concepts.

I designed these projects to be interdisciplinary, in accordance with the middle school interdisciplinary team philosophy. The projects covered aspects of these fields: math, science, technology, language arts, and social studies. For this research project, I will focus on the mathematical concepts evident in the students' work. An analysis of the concepts learned in other disciplines can be found in the appendices, and may be of interest to other teachers wishing to implement interdisciplinary projects of their own.

For each project, a subset of the national standards for math (NCTM) were identified. This subset represented the desired content knowledge students should demonstrate understanding of through their artifacts. Each stack was then examined for evidence of understanding of these standards.

As described by Patton (1987), a process of triangulation was employed involving the collection of data from multiple sources. These sources included field notes, videotapes, teaching and learning artifacts, and student and teacher interviews. Comparison between multiple sources helped to confirm or refute emergent themes.

Trustworthiness

Fetterman (1984) states that the researcher needs to be explicit with regard to his biases to negate their impact upon the research. To that end, I make explicitly known that I was the teacher of record, and disciplinarian for the students participating in the study.

Trustworthiness, as described by Lincoln & Guba (1985), is the argument that the findings of a study are "worth paying attention to (Lincoln & Guba, 1985, P. 290). Lincoln & Guba (1985) list four issues surrounding trustworthiness: credibility, transferability, dependability, and confirmability. Credibility measures the truth value of the findings of a study. Transferability is the extent to which the findings of the study can be applied to other contexts. Dependability is the criteria upon which the replicability of a study is judged. Confirmability is the measure of how well the data from the study support the findings of that study.

Credibility

I used three techniques to address credibility: Prolonged engagement, persistent observations, and triangulation. Prolonged engagement refers to staying in the field until "saturation" occurs (Lincon & Guba, 1995). I was the teacher of record for the students engaged in the study, and was present in the classroom every moment they worked on their projects during class. As classroom teacher, it was my job to engage in persistent observations - the constant and tentative analysis of what is taking place during the study. Viner (See Appendix G) provided a sounding-board for my tentative analyses. These sounding-board conversations were videotaped for analysis. Triangulation is the employment of multiple sources of data to illuminate the study from alternative perspectives. Videotape, interviews, artifacts, and field notes form the basis of triangulation for this study.

Transferability

In naturalistic study, transferability requires describing and interpreting the context and environment of the study. The setting, time, place, participants and events combine to describe a culture in which the learning took place. I provide a “thick description” so that the reader can make an informed decision as to whether or not this research is applicable, or transferable, to their particular situation. This point of view is consistent with Lincoln and Guba (1985).

Dependability

In a naturalistic setting such as a classroom, variables are difficult if not impossible to control. To counter this, Lincoln and Guba (1985) suggest the detailed and accurate documentation of the events, changes, and surprises which occur during the study. I provide such documentation through analysis of videotape, observations and field notes.

Confirmability

As data were collected and classified, an audit trail was kept in accordance with Halpern's six audit trail categories:

> Raw data, including electronically recorded materials such as videotape, written field notes, unobtrusive measures such as documents and records and physical traces.
> Data reduction and analysis products, including write-ups of field notes, summaries such as condensed notes, unitized information (as on 3x5 cards), …concepts and hunches.
> Data reconstruction and synthesis products, including the structuring of categories (themes, definitions, and relationships); finding and conclusions (interpretations and inferences) and a final report in connection with the literature.
> Process notes, including methodological notes (procedures, designs, strategies, rationale); trustworthiness notes (relating to credibility, dependability and confirmability and audit trail notes).
> Materials relating to intentions and dispositions, including the inquiry proposal; personal notes (reflective notes and motivations); and expectations (predictions and intentions),
> Instrument development information, including …preliminary schedules, observations. (Halpern, 1983, in Lincoln and Guba, 1985, p. 319 –20).

Other Research on This Same Classroom

During the 2001-02 school year, Mark Viner and I conducted our respective dissertation research in my mathematics classroom. This was done with the full knowledge and approval of our respective dissertation committees.

Since our dissertations study different aspects of the same population, during the same time period and during the same treatment, several aspects of the data will understandably be similar. Student quotations during videotaped interviews, teacher observations, and the students' artifacts will notably be identical. The themes, questions, and analyses of these items are distinctly different, and seek to illuminate different research questions.

The reader may wish to consult Mark Viner's dissertation for additional information about this project-based classroom:

Viner, Mark (2003) Observations and exploration of a sequence of design environments: Students designing a series of multimedia projects. Ph.D. dissertation, Kansas State University, United States -- Kansas.

CHAPTER 4 - Data

Goal of the Study

The goal of this study is to explore the use of interdisciplinary PBL projects for teaching mathematical concepts according to NCTM (2000) goals for mathematics instruction. These projects involved computer modeling software. The initial guiding question was: What are the teaching issues and evidence of student learning of mathematical concepts over a series of three interdisciplinary PBL projects involving STELLA™ modeling software which are designed to engage students, integrate technology, and provide a context for learning mathematics based on the 5 NCTM (2000) goals? The data gathered belong to two variable clusters: teaching, and learning. Two sub-questions were developed relating to the two variable clusters:

1) What are the issues related to teaching mathematics concepts in a technology-rich, interdisciplinary PBL project that follows the 5 NCTM (2000) goals?
2) What are the issues related to learning mathematics concepts in a technology-rich, interdisciplinary PBL project?

Participants were required to investigate three integrated, collaborative, real-world situations as modeled via STELLA™ and other dynamic modeling software. HyperStudio™ authoring software was used as a publishing medium for students to create artifacts of their understanding for authentic audiences. Observations and descriptions of the projects and events surrounding the creation of these artifacts were recorded, as well as observations concerning the beliefs and opinions of the students through the course of the three projects.

Overview of the Projects

A series of three projects were assigned through the course of the school year. The projects were designed to increase in difficulty and complexity over time. I provided scaffolding such that as students became more proficient with the technology, they needed less help from me.

Project I: Easter Island

The first project asked students to interpret the results of a computer simulation run by STELLA™ dynamic modeling software. Students created HyperStudio™ stacks to explain their understanding of graphing concepts, and the cause-and-effect relationships between the variables being graphed. The timeline for this project was approximately 3 to 4 weeks. Students worked on the projects Mondays through Thursdays.

Project II: The Dam Project

The second project required students to role-play in order to justify various perspectives on water management practices. Students used STELLA™ to make predictions, formulate and analyze decisions and provide convincing arguments based on data. HyperStudio™ stacks were created to communicate these decisions to authentic audiences. The timeline for this project was expected to take 3 to 4 weeks. Fridays were added as an additional day to work on the project.

Project III: City of the Future.

The final project required students to create a "polished" or well-done product. Students were required to design a city that ran efficiently on renewable energy sources. They produced an energy budget based on their own daily use of energy, and extrapolated to the population of a whole city. This project incorporated design skills learned in the previous projects to create a HyperStudio™ "advertisement" designed to stimulate people to come live in their city. The timeline for this project was approximately 3 to 4 weeks. Students worked on the project Mondays through Fridays.

Available Technology

The students worked on 11 networked 486 PC computers located in the math classroom for the first two projects. For the final project, a new computer lab was available such that each student had access to a computer. The students also had access to a photographic scanner, a digital still camera, and a VHS video camera for the incorporation of images into the students' designs.

Implementing Project 1: Easter Island

The "Driving Question"

The Easter Island project was introduced with an article about the 2001 California energy crisis. This article referenced the cause-and-effect nature of the relationship between population growth and energy consumption. Students then viewed a video about the history of Easter Island (Rapa Nui). Connections between what happened in the past on Easter Island and what happened with the 2001 California energy crisis were made explicit. Students were presented with the scenario of assuming the role of a World Health Organization worker, traveling back in time to answer the question "Can you help Easter Island (Rapa Nui)'s residents avoid a population 'meltdown'?"

The Easter Island Simulation

The Easter Island Simulation was constructed using the STELLA™ modeling software. The idea for it was taken from the sample models which were installed as part of the STELLA™ package. The original model was significantly modified because this was the first simulation the students had encountered in STELLA, as well as their first PBL-style lesson of the year. I did not want to overwhelm them with the complexity of the full model, so I separated it into three experiments.

At the beginning of the simulation, students were given a handout with a brief explanation of the project (See Table 5):

Table 5. Initial student handout, Easter Island project.

The year is 2100, and the Earth's population is out of control. People are starving; there just isn't enough food to go around. Everything's in short supply – water…electricity…toilet paper. The environment's a mess – it's not a nice place to be.

You are an employee of the "World Health Organization" and have been assigned the not-so-wonderful task of finding a way out of what seems like an unavoidable Global resource meltdown.

Fortunately, you remember something from 8th grade Algebra class – all those years ago – something about "Easter Island."

You jump in your "Way-Back" time machine and zip back to the year 1000 to study the Rapa Nui people. They experienced the same situation the world's in today…maybe by experimenting with them, you can find the solution to the world's problem.

Your assignment:

Try altering the world of the Rapa Nui people. See if you can find a way to avoid the disasters that occurred there – and maybe you can save the world!

Experiment #1

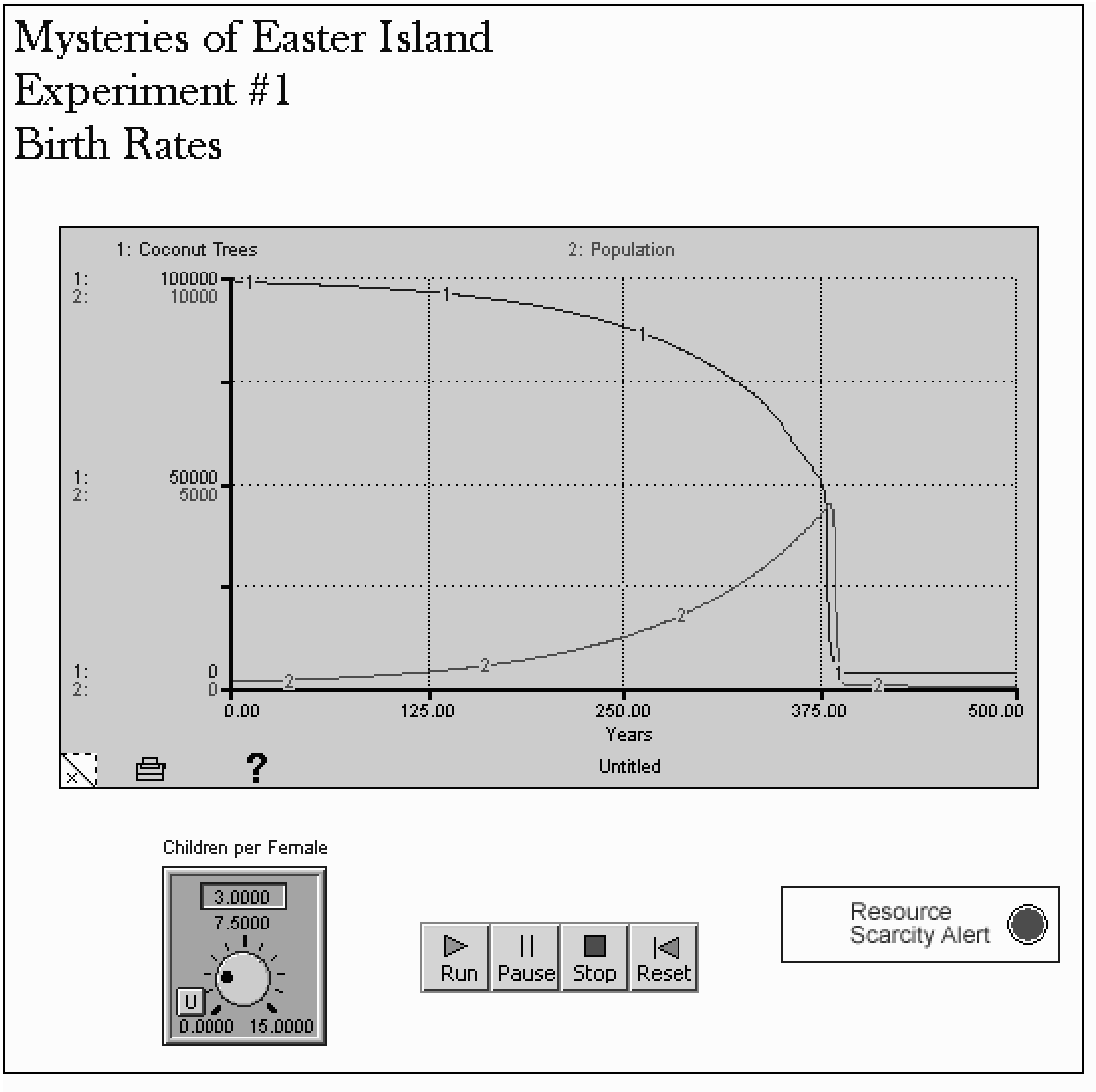
For each experiment, an additional page of instructions specific to each subproject was also provided. Table 6 shows the student handout for Experiment 1 of the Easter Island Project.

Table 6. Student handout, Easter Island Project, Experiment 1.

Experiment 1
It has come to our attention that our world is heading toward a population and resource disaster that could wipe out our entire world. You are hereby directed to utilize Time Travel to go back in time and study the population of the Island of Rapa Nui, also known as Easter Island. Archaeological evidence shows their island suffered exactly the same fate as we are currently facing.   Please try and alter their history by the use of STELLA modeling and HyperStudio.   (They will think it's magic!) Find a workable solution for the number of babies each woman can have. They need a population of more than 1000 people by the time the Slave ships come in 1800 (that's 300 years into your simulation), without causing a population meltdown. When you have a solution, make a HyperStudio presentation to their leader, the High Exalted Chief M'Viner, detailing what will happen in the future, and how your solution for birth rates will solve the problem. DON'T TELL THEM ABOUT THE SLAVE SHIPS YET!!!

The students were then given a simulation file to run in their STELLA™ console.   The console (See Figure 2) gave them control over the number of children born to each female of child-bearing age in the simulated population.   Though this was the only variable the students could control, within the structure of the simulation this one variable had profound effects on the simulated population.   More people required more resources (coconut trees, in this simplified case), which had a limited capacity to renew themselves (20 years, in this case). When the quantity of coconut trees declined, so did the population.   The simulation required the population to consume trees at a rate of 0.025 trees per year, but was constructed such that fewer available trees would cause the average lifespan of the simulated population to decrease, and the death rate to increase. In Figure 2, the original graph of what is historically believed to have happened on Easter Island is shown.

Figure 2. STELLA Console showing Easter Island Experiment #1.



There were two controls in this first simulation, a child-birth “dial” and the runtime control buttons. Students could manipulate the “dial” with the computer mouse to increase or decrease the total number of children per female. Once they had set that variable, they would click the “run” button and watch as the simulation ticked its way through the simulated 500-year time span. They could pause, stop, or reset the simulation at any time. The “Resource Scarcity” indicator would flash yellow when roughly one-third of the trees were gone and red when more than half were gone.

The graph in figure 2 shows the historical “population meltdown” that corresponds to the overuse of resources as a result of overpopulation. (This is an oversimplification of what actually happened, historically.) In Experiment #1, students were to use guess-and-check problem solving strategies, as well as their understanding of graphical representations to achieve the goal of 1000 persons sustainably living on Easter Island by the end of the time span.

Students then used HyperStudio™ software to create an artifact designed to persuade the leadership of Easter Island to understand the issues contributing to their population dilemma. This use of technology within a contextualized problem solving environment is consistent with PBL Goal 3, technology tools for cognitive and communication tools, as well as NCTM's (2000) Goal 2 of technology integration.

Experiment #2

After students had achieved a workable solution to Experiment #1, and had incorporated their results into their HyperStudio stacks, they were given a new task sheet and simulation file for their second experiment (See Table 7).

Table 7. Student handout for Experiment 2, the Easter Island project.

Assuming you've achieved more than 1000 persons by the end of your simulation, you're now ready to add the next piece to the puzzle. Using file "Easter Island 2" you now have control over replanting of Coconut trees. Remember the island can only carry 100,000 coconut trees. Your goal is to aid the Rapa Nui in a replanting campaign. Decide how many trees each person should replant. REMEMBER, trees don't produce fruit the next day!! They take a while to grow!! Don't expect changes to happen overnight!! Arrange it so you can sustain a good harvest of coconut trees, and make it so we have as many people as possible by the end of 500 years WITHOUT A MELTDOWN! The SLAVE SHIP is coming, and they're bringing DISEASES!!! (Don't tell the natives, they'll panic!) When you have a working solution, add to your report for High Exalted Chief M'Viner.

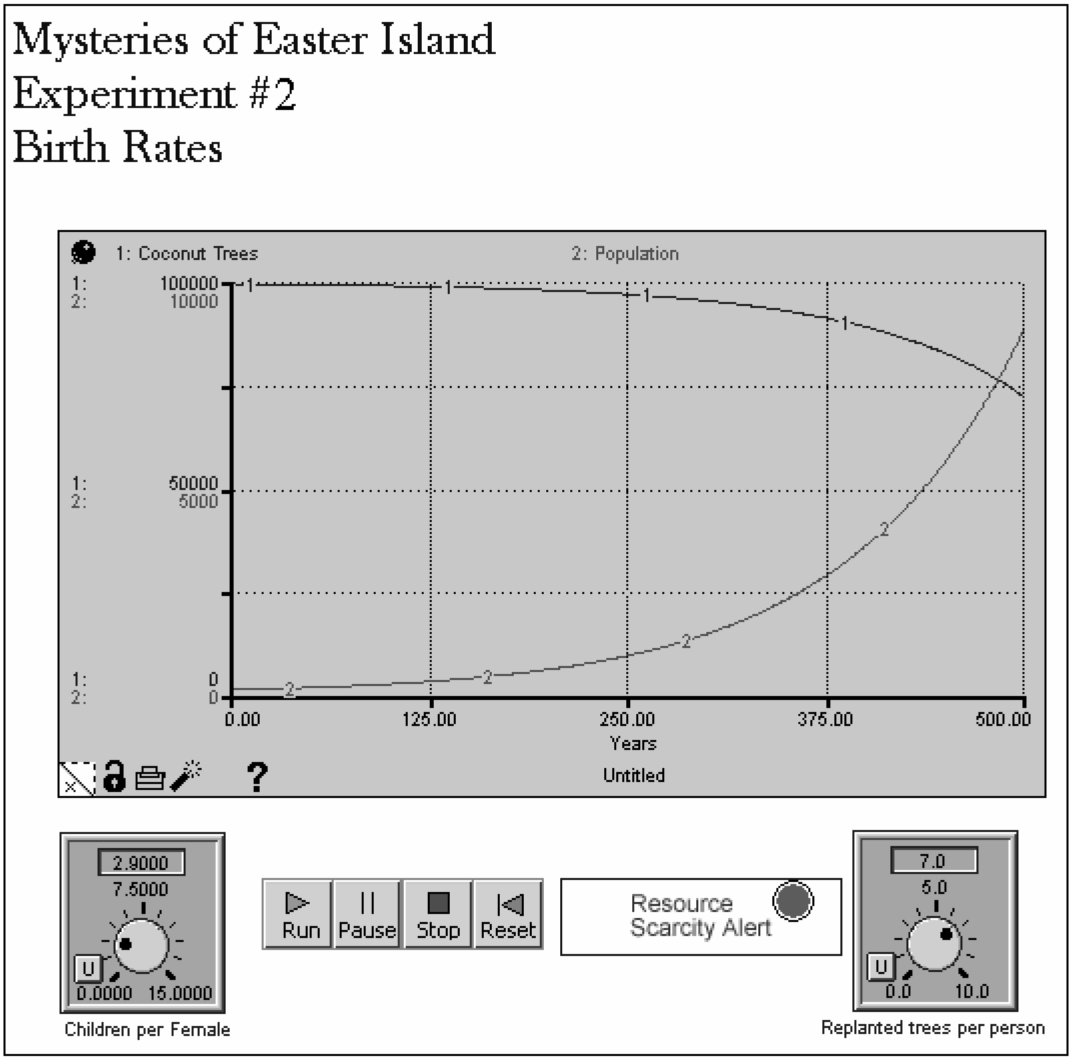
Attached to this handout was a brief message providing feedback from the fictional leader of the Rapa Nui (See Table 8).

Table 8. First Feedback from the High Chief

From High Exalted Chief M'Viner: Make sure your report is easy to understand. I will be taking your reports back to modern civilization in order to save future generations. Remember, that most people do not have the understanding or knowledge that you do and a good story will help them understand. Be sure to include a title card (an introduction) for your opening report and include all graphs and models. Good Luck!

The second simulation console incorporated a new control element, which allowed the students to simulate each person replanting a variable number of coconut trees during their lifetime. The coconut trees required 20 years to mature before their fruit would become available to the simulated inhabitants (See Figure 3).

Figure 3. STELLA™ Console, Easter Island Experiment #2



Students were given time to arrive at a workable solution, and to incorporate their results into their HyperStudio™ stacks.

Experiment #3

For the third and final part of the Easter Island project, students received another task sheet and simulation file (See Table 9).

Table 9. Student handout, Experiment #3, the Easter Island project.

We've been monitoring your progress; we're relatively pleased with your results. We've got a new suggestion for you - why not decide WHEN the Rapa Nui should start implementing your suggestions, rather than just forcing them from the start. When you check your "Easter Island 3" model, you will notice some new things: First, and most important, are the sliders. These are time delays - you can decide at what year the Rapa Nui begin using your ideas. You can still set the birth rates at the very beginning, but you now have the ability to change the birth rate after a period of time. You also now have control over when the Rapa Nui start replanting trees. There is a slider under "Replanting" that will let you specify what year this happens. We'll assume no replanting takes place until the year you specify. Remember, this is all in preparation for the day the SLAVE SHIPS arrive! (Don't tell the Chief - he'll just worry.) We need the most people we can get without "meltdown" and without going off the graph! (That's the most important thing - some of your earlier models have populations in the hundreds of thousands - the maximum you should ever have is 10,000 people! Otherwise it's just icky and crowded. It's a tropical island, and when there are so many people, the smell of body odor is absolutely gagging! (Don't tell the Chief I said that…).

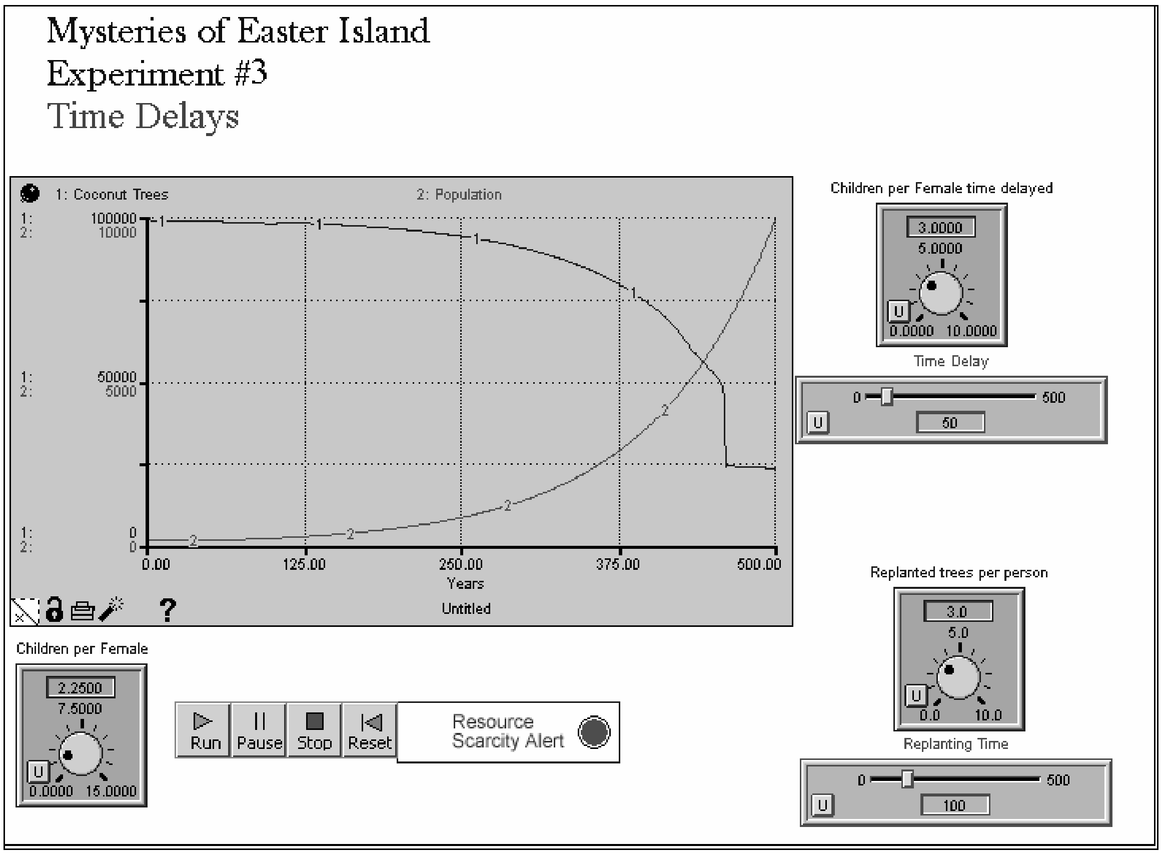
Attached to this handout was another brief message providing feedback from the fictional leader of the Rapa Nui (See Table 10).

Table 10. Second Feedback from the High Chief.

Message from the Great M'Viner: Great start on your Hyperstudio stack. I liked the way you made it interactive. My people, however, are having a hard time understanding it. Perhaps if you combined your two stacks into one and then made sure it was easy to navigate (buttons on all the pages) they would understand it better. My people are also very visual. They like shiny things, like pictures and stuff. Good Luck!

The simulation console for this experiment included several new features (See Figure 4). In this simulation, students could set an initial birth rate, and also a time-delayed birth rate. Students could also set a replanting rate and time-delay it as well.

Figure 4. Simulation console, Experiment 3, the Easter Island project.



Due to time constraints, we did not have the opportunity to investigate what would happen when the Peruvian slave ship arrived at year 300 of the simulation, nor what happened as those slaves returned to the island in following years carrying smallpox. This would be an area for further research.

The Content Goals

The content goals for "Easter Island" project were to have students investigate exponential growth and decay, and the cause-and-effect relationship between variables over time. Integrated curricular themes from Technology, Social Studies, Language Arts and Science included concepts of limiting factors of ecosystems, carrying capacity, resource utilization and allocation, and fair-use practices.

In accordance with the NCTM (2000) goal #1 (learning with understanding), fifteen content and instructional mathematics standards were selected from NCTM (2000) (See Table 11).

Table 11. Content and Concepts covered by the Easter Island project.

NCTM Standards and Benchmarks: All students in grades 6-8 should --
Number and Operation • (1.1.1) Work flexibly with fractions, decimals, and percents to solve problems **Algebra** • (2.2.2) Explore relationships between symbolic expressions and graphs of lines, paying particular attention to the meaning of intercept and slope. • (2.3.3) Model and solve contextualized problems using various representations, such as graphs, tables, and equations. **Data Analysis** • (5.1.1) Formulate questions, design studies, and collect data about a characteristic shared by two populations or different characteristics within one population. • (5.1.2) Select, create, and use appropriate graphical representations of data. **Problem Solving** • (6.1) Build new mathematical knowledge through problem solving • (6.2) Solve problems that arise in mathematics and other contexts. • (6.3) Apply and adapt a variety of strategies to solve problems. • (6.4) Monitor and reflect on the process of mathematical problem solving. **Reasoning and Proof** • (7.2) Make and investigate mathematical conjectures • (7.3) Develop and evaluate mathematical arguments and proofs. **Communications** • (8.2) Communicate mathematical thinking coherently & clearly to peers, teachers, and others; **Connections** • (9.1) Recognize and use connections among mathematical ideas. **Representations** • (10.1) Create and use representations to organize, record, and communicate mathematical ideas. • (10.3) Use representations to model & interpret physical, social, & mathematical phenomena.

Expectations for students participating in this project included interpreting and manipulating computer-generated graphs, translating between graphical and verbal descriptions, writing for authentic audiences, revising and refining results based on further evidence.

Collaboration

Collaboration is a common goal between NCTM (2000) and Blumenfeld's et al. (1991) goals for PBL (Specifically, NCTM (2000) Goal 5, and PBL Goal 2). To honor these goals, Students were allowed to work in pairs to solve "The Mystery of Easter Island". These pairs were self-selected, with five students opting to work alone. I acknowledge the fact that allowing five students to work non-collaboratively appears to be in opposition to the collaboration goal. The reader should understand that in the interactions between peers and peer groups, the entire class was a form of collaborative group as is detailed later in this chapter. I also felt that the goal of Diversity and Flexibility, in terms of learning and working styles, was of higher importance for this project.

Diversity and Flexibility

To honor NCTM's (2000) Goal 3 of diversity and flexibility, I felt that it was necessary to build ownership of the evaluation process so that assessment would not be external to the students. Having students describe the criteria for a "good" project would encourage buy-in and produce better results both in product and behavior. Table 12 shows the criteria classes A and D came up with through their brainstorming activity:

Table 12. Classes A and D grading criteria for Easter Island project.

Class A:
How much effort the students put into the project.
Students must have good cooperation between partners.
Proper spelling, grammar and punctuation must be used.
Creativity should be unique. Students need to go above and beyond the project and give attention to detail.
The HyperStudio™ stacks need to be understandable to the intended audience.
Students need to create a good explanation of the data (a story-line).
The stacks need to have good information (the information needs to be accurate).

Class D:

The project needs to be fun and interesting (the inclusion of pictures and sounds)

The intended audience should learn something from the stack

Stacks should contain good descriptions (words, basic facts, graphs, and data).

The stacks should be organized (they need to make sense).

The stack should be interactive. It should ask the user questions.

The meat should be before the gravy (stuff before fluff).

The students should use animations to make it interesting.

The projects need to be done on time.

Authentic Audience & Reflection

As students arrived at a workable solution to save the Rapa Nui people (based on their graphs), they created a HyperStudio stack to explain the history of Easter Island and their solution to the problem to someone unfamiliar with the project. To provide some structure and consistency to their final product, five additional requirements were imposed:

1. The students need to provide accurate information
2. The students need to provide a history of the Rapa Nui people
3. The stacks need to have a story-line
4. The students are required to make the stacks interactive
5. The stacks need to contain appropriate graphics and sound.

As the students neared completion of their projects, I noticed students were experiencing difficulty in writing descriptions of the graphical representations of their data. The Language Arts teacher (T-2) on the team was brought in to assist students in their writing process. The teacher (T-2) implemented four guidelines:

1) The learners need to introduce themselves, their positions, and their purpose for visiting the Rapa Nui people.
2) The students were required to let the chief of the Rapa Nui know that they were familiar with his tribe and history. The students needed to demonstrate that they respected the Rapa Nui beliefs and traditions.

3) The stories needed to explain the graph and demonstrate to the Rapa Nui how they would experience a "meltdown" if they did not make appropriate changes in their way of life.
4) The story needed to appeal to the Chief's heart (persuasive writing).

In addition, pairs of students verbalized to each other what their graphs meant. The other student would type down the explanation precisely as verbalized to aid in the writing process and self-reflection (NCTM Goal 4).

Peer Assessment Activity

The Language Arts teacher (T-2) asked her classes to conduct a peer review of class A and D's stacks (an authentic audience, as per PBL Goal 4). Sample stacks from A and D were projected, and T-2 modeled how to give constructive peer reviews of them. Students were assigned stacks at random, and allowed to browse through the stacks individually or in groups. Student-reviewers were given the option to opt out of reviewing particular stacks if they felt it necessary to do so.

As these peer reviews were conducted, members of classes A and D (the authors of the stacks being reviewed) asked that they might be present during the sharing-out of evaluations, to answer questions and observe the process.

Following the peer review, classes A and D reflected (NCTM Goal 4) on the comments of the peer reviewers and created a list of changes they needed to make. Class D then did a blind review (meaning, the authors' identity was hidden) of class A's stacks and, vice versa. Once again, the authors reflected on the comments of the reviewers and made changes based on these recommendations. The students were given extra time to implement these changes before the final design was due.

At then end of this project, class D was dropped from the study. The student population in the study school was highly transient, and as new students enrolled it quickly caused a class size imbalance in classes B and C. Eventually, I decided to release class D to maintain amicability among my colleagues. Students were given the choice to switch to class A, or drop from the study. Several students in class D were moved into class A.   The stacks of those students who were dropped from the study are not represented in the data.

The Teaching

Each of the three simulations in this study is an artifact of teaching. They form the core of the content and concepts students encountered during each of the three projects. In this section, I will describe in detail the mathematical concepts, as recommended by the NCTM (2000) standards that were necessary to effectively work with each of the simulations.   I will be referring to NCTM Standards, Benchmarks, and Indicators (SBI's), which are enumerated in Appendix B.   The naming convention I will use is: Standard.Benchmark.Indicator (e.g. 1.1.1 means Standard 1, Benchmark 1, Indicator 1).

The Math in the Easter Island Simulation

Number and Operation

The Easter Island simulation provided variables whose values could be manipulated through the use of a slider or dial. The range of values these variables could be assigned were positive rational numbers rounded to the ten-thousandths place.   The graphical interface of the simulation console allowed students to place their cursor anywhere on the graph to trace the exact value of anything being graphed. For this simulation, the graph showed the population of people and coconut trees over time as positive rational numbers to the hundredths place.

In their interactions with the variable-setting tool and tracing values on the graph, students would have needed to "work flexibly with fractions, decimals, and percents to solve problems" (SBI 1.1.1), which are commonly referred to as "rational numbers"

Algebra

There were three content goals under algebra relating to the Easter Island project: conceptual understanding of variables, exploring relationships between variables, and visual modeling of variables.

In the Easter Island simulation, students were given control of three variables: births, replanting trees, and time delays. As they manipulated these variables, students were "develop[ing] an initial conceptual understanding of different uses of variables" by "explore[ing] relationships between symbolic expressions and graphs of lines, paying particular attention to the meaning of intercept and slope" (SBI 2.2.1 and 2).

Additionally, by exploring variables and graphs, students were also "model[ing] and solve[ing] contextualized problems using various representations, such as graphs, tables, and equations" (SBI 2.3.1). It is interesting to note that because this project's real-life context had an exponential nature, the project exceeded the NCTM (2000) SBI 2.4.1, which only asks eighth graders to "use graphs to analyze the nature of changes in quantities in linear relationships." Non-linear relationships are a high school concept, according to NCTM (2000).

Data Analysis, Representations, Communication

The three content benchmarks of Data Analysis, Representations, and Communication are linked together in this project, as the analysis of the simulated data takes the form of a change-over-time graph, which is a representation. This graphical representation was used to communicate the meaning of the data.

The real-world context of the Easter Island project required students to "formulate questions, design studies, and collect data about a different characteristics within one population" (SBI 5.2.1), specifically the number of children born to females on the island and their use of coconut trees. Students were also required to "select, create, and use appropriate graphical representations of data" (SBI 5.2.2), in this case a change-over-time graph, in order to explain their findings in their HyperStudio™ stacks.

Students were required to create a HyperStudio™ stack through which they communicated their findings to the fictional Chief of the Rapa Nui. In this way, students effectively "communicate[d] mathematical thinking coherently & clearly to peers, teachers, and others" (SBI 8.2) even though the other in this case was a fictional person.

While the Easter Island model focused on a graphical representation of two quantities (population and resource), students were "use[ing] representations to organize, record, and communicate mathematical ideas" SBI(10.1) as they explained their solutions to the Rapa Nui.

These “representations [were used] to model & interpret physical, social, & mathematical phenomena” (SBI 10.3), such as population growth and resource utilization over time.

Problem Solving

The Easter Island project was perhaps most effectively solved using problem solving techniques of "Guess-and-Check", and "Look for a Pattern" (NCTM 2000). Even so, students did “build new mathematical knowledge through problem solving” (SBI 6.1) while “solv[ing] problems that arise in mathematics and other contexts” (SBI 6.2) such as population growth and resource management. Students were required to “apply and adapt a variety of strategies to solve problems” (SBI 6.3) such as guess-and-check, and then try their solution attempt out on the simulation while “monitor[ing] and reflect[ing] on the process of mathematical problem solving” (SBI 6.4) as it related to their goal for each of the three sub-experiments.

Reasoning and Proof, Connections

Reasoning and proof, as a content goal, is integrated into the goal of Connections in the Easter Island simulation, as the conjecturing and arguing from data that was required by the project formed the basis for connecting new knowledge to prior knowledge. For example, reasoning that a larger number of children born would cause the graph of the population to change in a predictable manner is a connection to understanding the cause and effect nature of the variables values, graphs of nonlinear functions, and patterns of change.

Formal proof was not a goal for this project, however reasoning about the results of their manipulations of variables was. By adjusting the variable values, students were effectively “mak[ing] and investigat[ing] mathematical conjectures” (SBI 7.2) in the process of “develop[ing] and evaluat[ing] mathematical arguments and proofs,” (SBI 7.3), even if the proofs were extremely informal in nature.

Students were given assistance throughout this simulation as they encountered a hole in their understanding of such things as what it means when the graph goes off the page. This information spread quickly among the students, as many times the first person to ask the instructor for help quickly became the go-to person for help on that topic. In this way, students began to “recognize and use connections among mathematical ideas” (SBI 9.1) as they built their understanding through dialogue and experimentation.

Summary of Teaching Issues

Resources & Space

From time to time as they worked on their projects, students would become "stuck" and need teacher assistance, but had to wait for a teacher to be available. This was a source of much frustration among participants, as was the limited amount of resources, such as CD-ROMs of clipart, which were frequently unavailable. Students also expressed discomfort at the crowdedness of the classroom, and the necessity of sharing the computers.

Partnerships & Grouping

Working in collaborative partners presented a problem initially, as I had chosen who would work with whom. Since this was partner work, one participant had control of the computer while the other observed and made suggestions to the operator, which led to some discord. I attempted to fix some of the group dynamics problems by reassigning group members, but eventually had to allow some of the students to work on their own.

Complexity of the Task

The STELLA™ model had to be broken down and simplified, as students were having difficulty explaining, in writing, the graphical and tabular data the simulation generated. The students seemed to have difficulty in describing what was happening to their graphs (converting from graphical to verbal representations). The Language Arts teacher (T-2) was brought in to assist the students. While this did help initially, students complained that T-2's suggestions limited their creativity and ownership. Students complained that the stacks all started to look similar, and that they felt they did not have the freedom to create their stack as they wanted.

While students exhibited facility in using the computers, they seemed to have difficulty in understanding that their solutions to the posed problem might not be the same as those of their peers. Repeatedly, the researcher had to assure the students that there was not one "right" answer to the problem.

Constant Monitoring, Adjustment, and Time

Originally, the first project's scenario was to be "Attack of the Killer Mosquito," which involved triage and treatment of a simulated human being in distress. The first project was to being in October, 2001.   In September of 2001, terrorists destroyed the World Trade Center in New York. The school principal felt (and I agreed) that a scenario involving a crisis such as "Attack of the Killer Mosquito" was ill-advised.   This is why project #1 became "The Easter Island Project" instead.

The Easter Island scenario was initially to complex, and had to be adjusted. It was broken down into thee sub projects which were much simpler and provided a form of scaffolding for student understanding.   Originally this project was to run for three weeks, but due to the adjustments actually took six.

Since this was the first PBL-style project the students had ever done, they needed reassurance and occasional guidance throughout the course of the three experiments.   These took the form of notes, additional guidelines for their artifacts, and one-on-one conversations.

By continuously monitoring the situation, I was able to make these adjustments both to the logistics and requirements of the project, as well as lengthening the time frame to accommodate the changes that were made to maximize the educational impact of the project.

The Learning

Number and Operation

Nine out of the ten Easter Island stacks referenced rational numbers in their solutions for the Easter Island scenario.   Stack 7a's authors did not reference any numerical values at all in their description of their solution. This does not necessarily indicate the students do not understand rational numbers, simply that there is no evidence that they do understand rational numbers.

As I observed students working, initially they did not seem to comprehend why the "children born" control was graduated into hundredths. After some discussion of what it would mean to a population of 100 women to have a birth rate of 2.5 children per female, students finally hit upon the idea that it was an average – that some women would have three children, others two, and on average it would work out to 2.5 children per female. From there on there was little confusion (See Table 13).

Table 13. Sample quotes relating to use of rational numbers, Easter Island project.

G8: At first I didn't really get it…it was like 2 point something . I was like how is somebody going to have 2.5 kids, I don't know . Then G6 explained it to me and I was like ok.
G4: Rounding, like if you have 2.1 and it's still crashing you can go to 2.5 and if that doesn't work you can go to 3 or other numbers in-between.

Algebra

Six out of ten stacks showed evidence of understanding variables, ten out of ten explored the relationships between variables, and ten out of ten successfully modeled the variables visually. While the four stacks that did not show evidence of conceptual understanding of variables did include representations of the variables of births and coconuts available and the relationships between them, those stacks did not include a description of what the variables meant in this context.

From observations, students seemed to grasp quickly the way the simulation worked with respect to the coconuts and the births. Students also picked up on the fact that more people born would eventually lead to more coconut trees being replanted.

Table 14. Sample quotes showing student understanding of variable relationships.

B1: Plant a lot of trees and make the birth rate go down
G3: figured out the number of trees that you could eat so that the population doesn't go down. Have it all balanced out to see how coconut trees a person could have.
G8: you have to replant in a certain year. Have a certain number of kids. As more people come in, they plant coconut trees and have that number of kids to replant the trees…something like that.

Data Analysis, Representations, Communication

In order to show understanding of the two indicators under Data Analysis and the two indicators under Representation, a stack had to have a graphical representation of the simulation showing a workable solution. To demonstrate understanding of the communication indicator, the stack also had to include an explanation of the solution represented by the graph. All ten stacks met these requirements.

As this was a purely organizational set of indicators, there was no data in the interviews to indicate understanding. Observationally, however, this is the point in the study where T-2 was asked to come into class to help students to explain their graphs. This intervention was successful, as every student was eventually able to do so.

Problem Solving

The problem-solving indicators were process-based: building new knowledge, solving problems, applying strategies, reflecting. There was limited evidence in the stacks of these indicators, however the explanations presented in the stacks would not have been possible without a solution, and the solution to the simulation required all four content goals. Observationally, students seemed to use guess-and-check problem solving predominantly, and look-for-a-pattern secondarily.

Table 15. Sample student quotes relating to problem-solving strategies.

B1: I would leave the coconut trees all the way to the top so it wouldn't run out and I would just mess around with the other one.
G2: Usually when you start out like if you just open it and you have like seven kids and zero trees ….you need to change those so those kids can be more and more trees being planted. So you have enough trees for enough people. You just kind of play with it. You know, try five or six or go from seven kids to two kids. If that is too low just start messing around.
G3: I would increase the number of coconut trees and decrease the population , kind of even it out for a little bit.
G5: We mess around with the dials until we found it. I would pick a number at first and see what it would do and as I see the graph then I would be able to make a little decision on where to go, which way , more or less.

Reasoning and Proof, Connections

The ways in which students formed and tested conjectures in the Easter Island project was closely related to their connection-forming. Students demonstrated proportional reasoning in all ten stacks, as well as in their descriptions of the scenario during interviews (see Table 16).

Table 16. Sample student quotes showing reasoning and proof and connections.

G4: The people are growing but they are eating too many coconut trees. They get their people up (referring to the line on the graph) but [there] ain't no food so they all crash.
G5: You see right here they started off eating and eating and eating too much coconuts. That's why the population of coconuts trees are decreasing.
G6: The more people the less coconuts and it keeps going
G7: Ya they are just like cutting down the trees so they just go down there, eat more food and they are not replanting or anything .
G8: It's saying the coconut tree population is going down and the people population goes up but then increases and overlaps with the coconut trees and then at the end they are no coconut trees or people.
G9: Ok the more people there are, then the coconut population is getting less, then the population of coconut trees and people just die out.

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Peer Review Data

Question 1: What was one of the best features about this stack?

Overwhelmingly, the student evaluators identified the pictures and background images as one of the best features. This is related to the second highest rating going to stacks being creative and fun. Navigation and the written explanations rated lowest (See Table 17).

Table 17. References to categories of analysis for Question 1, Peer review of Project 1.

	Stack Number										
Category	**1a**	**2a**	**3a**	**4a**	**5a**	**6a**	**7a**	**8a**	**1d**	**2d**	**Total**
The pictures/background	11	1	5	7	3	5	2	6	3	4	47
The written explanation	2	3	2		2	1					10
Stack was creative & fun				6		2	1	5	2	3	19
The overall layout/navigation					1		6				7

Question 2: Was the stack fun and interesting? What made it fun and interesting?

The student reviewers indicated how highly they value the multimedia aspect of HyperStudio in their answers to Question 2 (See Table 18). Lack of sound and graphics was the leading complaint with regard to stacks being fun/interesting.

Table 18. References to categories of analysis for Question 2, Peer review of Project 1.

	Stack Number										
Category	**1a**	**2a**	**3a**	**4a**	**5a**	**6a**	**7a**	**8a**	**1d**	**2d**	**Total**
Cool stuff – transitions/sound					2	2		1			5
The organization of the stack	1		1			1					3
Yes – no reason given	2		1	8	1		1	1	2	3	19
No – no reason given	3	2			3	1	1				10
No -didn't have sound/graphics	6	3	4	4	1	5	8				31

Question 3. Did you learn anything from this stack?

Twice as many reviewers indicated they had learned something from the stacks they reviewed as did not. Stack 8a showed the highest number of positive responses, while stack 4a showed the highest number of negative responses (See Table 19)

Table 19. References to categories of analysis for Question 3, Peer review of Project 1

	Stack Number										
Category	**1a**	**2a**	**3a**	**4a**	**5a**	**6a**	**7a**	**8a**	**1d**	**2d**	**Total**
No	2			7	4	3	5		1	1	23
Yes	9	3	6	3	1	5	5	11	2	4	49

Question 4. Did the stack have a good explanation of the data (graphs and charts)? What would you have done differently?

While the majority of reviewers agree that the stacks were good overall, the biggest complaint is in the explanations of the graphs. Stack 4a scored highest in needing to improve the explanation of their graphs, while 8a scored highest for having a good explanation (See Table 20).

Table 20. References to categories of analysis for Question 4, Peer review of Project 1.

	Stack Number										
Category	**1a**	**2a**	**3a**	**4a**	**5a**	**6a**	**7a**	**8a**	**1d**	**2d**	**Total**
Good explanation, no suggestions	3	3	3	3		6	2	10	3	5	38
Explain the graphs better	4		1	7	4		6				22
Make the stack easier to read	4										4
Make the stack more interesting			2		1	3	1				7

Question 5. Was a story used in this stack? Did you like it? Why or why not?

A majority of the stacks were rated as having a good story line. The single complaint against the story line category amongst all reviewers was spelling errors. Stack 8a rated the highest as having a good story line. Stack 4a rated highest as having a poor story line (See Table 21).

Table 21. References to categories of analysis for Question 5, Peer review of Project 1.

	Stack Number										
Category	**1a**	**2a**	**3a**	**4a**	**5a**	**6a**	**7a**	**8a**	**1d**	**2d**	**Total**
Story line is good	3	1	4	2	1	7	3	9	2	2	34
Story line is poor	6	1		9	3	1	7			1	28
Spelling errors	2										2

Question 6. What questions do you still have after reviewing the stack? What areas are unclear?

A majority of raters indicated the explanation of the graphs was the biggest problem among the stacks. Visual impression and persuasive writing scored highly. Stacks 1a and 5a seemed to give the impression of having inaccurate information (See Table 22).

Table 22. References to categories of analysis for Question 6, Peer review of Project 1.

	Stack Number										
Category	**1a**	**2a**	**3a**	**4a**	**5a**	**6a**	**7a**	**8a**	**1d**	**2d**	**Total**
Explanation of graph is confusing	4		3	2	2	2	3	1			17
Visual impression is poor	2			3			2	1	1		9
Needs more persuasion					1	1	5	1		1	9
Information seems inaccurate	4				1						5

Question 7: What are some suggestions to help this person improve their stack?

Peer reviewers rated the need to add sound and more information as the highest among their peer's stacks. The need to improve mechanics (spelling/grammar/punctuation) also rated highly (See Table 23).

Table 23. References to categories of analysis for Question 7, Peer review of Project 1

	Stack Number										
Category	**1a**	**2a**	**3a**	**4a**	**5a**	**6a**	**7a**	**8a**	**1d**	**2d**	**Total**
Add sound	6	1	3	3	1	2	3			1	20
Add more information				6	1		9	3			19
Mechanics (spelling/grammar)	5	1		2	1	4		1		1	15
Add graphics	1		3	1	1	1	4			1	12
Add color	2		3				1				6
Make it more interesting	1			1		1				1	4
Add animation	1	1									2

Question 8: Was the stack easy to navigate? Did the buttons work properly? Were they easy to understand?

A majority of reviewers rated their peer's stacks as easy to navigate. (See Table 24)

Table 24. References to categories of analysis for Question 6, Peer review of Project 1.

	Stack Number										
Category	**1a**	**2a**	**3a**	**4a**	**5a**	**6a**	**7a**	**8a**	**1d**	**2d**	**Total**
Not easy to navigate	5		2				1		1		9
Easy to navigate	4	2	4	12	4	7	8	10	2	3	56

Question 9: Did the stack provide accurate information? What mistakes did you find?

The reviewers showed themselves adept at spotting mechanical (spelling/grammar/punctuation) errors in their peers' stacks. Every stack had at least one instance of a mechanical error. Stacks 4a, 5a, and 7a seemed to have erroneous information (See Table 25).

Table 25. References to categories of analysis for Question 9, Peer review of Project 1.

	Stack Number										
Category	**1a**	**2a**	**3a**	**4a**	**5a**	**6a**	**7a**	**8a**	**1d**	**2d**	**Total**
Mechanics (spelling/grammar)	9	2	5	6	4	6	5	5	1	1	44
Mistakes in information				1	1		3				5
Sound did not work	1			1						1	3
Too short – make it longer				2							2
Navigation problems									1		1

Standards Evaluation

For the purposes of this research, each stack was evaluated against the NCTM (2000) standards selected for this project (See Table 26). As each project was developed, the content area standards, benchmarks, and indicators were considered to provide a means of evaluation for research. Only those standards that are relevant to the particular project are listed. A full documentation of the standards for each discipline may be found in the Appendices.

National Council of Teachers of Mathematics Standards Correlations

Stacks 1a, 1d, 2a, 2d, 6a, and 8a did meet the selected NCTM standards, as determined by me, teacher and researcher, whereas 4 stacks did poorly on 2 standards (See Table 26).

Table 26. Stacks showing evidence of meeting NCTM standards for Project 1.

		Stacks									
NCTM Standards	**S.B.I**	1a	1d	2a	2d	3a	4a	5a	6a	7a	8a
Number	**1.1.1**	X	X	X	X	X	X	X	X		X
Algebra	**2.2.2**	X	X	X	X				X		X
	2.3.3	X	X	X	X	X	X	X	X	X	X
Data	**5.1.1**	X	X	X	X	X	X	X	X	X	X
	5.1.2	X	X	X	X	X	X	X	X	X	X
Problem Solving	**6.1**	X	X	X	X	X	X	X	X	X	X
	6.2	X	X	X	X	X	X	X	X	X	X
	6.3	X	X	X	X	X	X	X	X	X	X
	6.4	X	X	X	X	X	X	X	X	X	X
Reasoning	**7.2**	X	X	X	X	X	X	X	X	X	X
	7.3	X	X	X	X	X	X	X	X	X	X
Communication	**8.2**	X	X	X	X	X	X	X	X	X	X
Connections	**9.1**	X	X	X	X	X	X	X	X	X	X
Representations	**10.1**	X	X	X	X	X	X	X	X	X	X
	10.3	X	X	X	X	X	X	X	X	X	X

Interviews

Unstructured interviews were conducted during class outside the classroom. Students were selected at random to be interviewed (this means, some individuals from partnerships may have been interviewed separately from their partner).

Question 1: What do you think about doing the projects so far?

The majority of quotes indicated that students enjoyed doing the projects. The primary reasons seem to be novelty and creativity. Negative comments seem to center on the repetitive nature of the simulation, and lack of instructor support time.

Table 27. Sample student quotes regarding students' thoughts about doing projects.

Positive Quotes
G3: It was interesting. It was actually kind of fun. Well, I have never done this kind of thing before. It was something new.
G6: I just liked the whole thing. Yes, like they said, we didn't get to do this before. Plus, I don't want to do regular math, so of course I'm going to like it and it's easier doing it on the computer.
G8: I think it's fun because we can create the cards the way we want them to be.
G13: I think that creating Hyperstudio™ projects are really fun and is a lot better than book work
B2: I like the Hyperstudio™ projects. They let me be creative and learn at the same time. It's fun, yet I'm still in school. Surprising!.
G10: It is fun typing and putting pictures and sound.
B4: [The] project is fun because you can make pictures and graphics. It also is sometimes hard because you have to plan out what your project is going to be about.
G6: We get to use our imagination to create something that could possibly be used as an example in-front of people everywhere to see how we learn.
B5: [The project] is a good way to use math and algebra in the real world.
G8: I like working on computers better than working in the book.
Negative Quotes
B3: I think it's ok but it gets boring because we keep doing the same thing. I know you are trying to get us to learn it and all but we are doing the same thing like word fractions and those types of things.
G2: It's frustrating sometimes because there are only two teachers in the class and you can be stuck for half an hour without getting any help.

Question 2: How can making a Hyperstudio™ stack help you understand the STELLA™ model?

The positive comments tended to indicate an appreciation for presenting information in a variety of formats, and the need to provide some sort of structure when explaining graphical data. Negative comments indicated that students did not see the connections between the simulation, and the HyperStudio™ stack. This may be an indication of the problems students were having in describing their results from STELLA™ in their HyperStudio™ stack, which prompted the T-2 intervention.

Table 28. Sample Quotes, Project 1, Question 2.

Positive Responses
B5: The HyperStudio™ stack gives us a visual as opposed to STELLA™ which helps us understand the problems and equations.
G7: Because you have a story to help describe what is happening and what you did, and there is the graph that shows you how or what percent or how much you have has been sold or made, or killed or something like that.
G9: Making a HyperStudio™ stack, I think, does help you understand the STELLA™ model. I think this because STELLA™ is just a model, but HyperStudio™ you can explain everything and even stick graphs on it.
G13: Making a HyperStudio™ stack does help me understand the STELLA™ model better because it is like a summary and breaks everything down in a simple way to understand.
B6: Sometimes a HyperStudio™ stack makes the STELLA™ model clearer because it breaks down the information into smaller pieces, so you can see everything one at a time, instead of only being able to concentrate on the whole thing. Notice how I began with sometimes. That's because it only works if you do it right.
Negative Responses
B7: Not really, because STELLA™ & HyperStudio™ are two different programs and they both tell you different thing in each program.
G8: No, not really. It may have a summary & graph & model but I have to have someone explain it.
G15: No, because the HyperStudio™ sometimes is a stack it is not the same as a STELLA™ model to me.

Question 3: Do you think you know just as much about graphs or graphing as students who didn't do this?

Most students felt that their class knew more about telling stories from graphs of real-world situations than those students not involved in the project.

Table 29. Sample Quotes, Project 1, Question 3.

G3: We know how to deal with words in math.
G4: …because they just know numbers, numbers, numbers.
G5: I think we know how to put stories into math better
G3: like how to put math problems into stories.

Summary of Learning Issues

Technology

Students seemed to have little difficulty in working with STELLA™ or HyperStudio™, as they worked autonomously and self-sufficiently on the project. Students were able to explain, at least verbally, their understanding of the graphs and variables. In many cases, the partners resolved their roles such that the one operating the computer explained what the graphs meant, while the other partner wrote the storyline, or decided on revisions to their stacks.

Audience

Students were observed mentioning the intended audience with respect to the peer reviews of their stacks. The prospect of having an outside reviewer seemed to provide a level of focus, as they knew their work was going to be evaluated by their peers.

It became apparent throughout the peer review that many of the students seemed to be seeing their own stacks for the first time. They began looking at their own stacks with the critical eye of a reviewer.

Creativity & Ownership

Students expressed that they preferred this kind of learning to paper and pencil, or reading out of a book. They especially liked having the freedom and flexibility of expressing themselves creatively through HyperStudio™ which is why some students disliked T-2's intervention, as they felt it took away some of their choice and creativity. At the end of the first project, students felt they could explain graphical displays of data better than their classmates who were not participating in the project.

Collaboration

Placing students into collaborative partnerships was initially problematic. Students expressed a desire to have well-defined roles when working in groups. They eventually formed whole-group collaborative partnerships, as students frequently left their group to provide technical assistance to members of other groups, or provided techniques for modifying the simulation variables to achieve the goal.

The Scenario

The scenario for the Easter Island project was flawed in two ways which are relevant to it being used as a PBL scenario: The scenario, in its limited form, had a very small set of "right" answers, which meant that once a few groups had found one of the possible solutions, that solution quickly spread through the entire group. The scenario was not as relevant to the students as I had hoped. Many students expressed their dislike for this scenario as it did not have relevance to their lives.

Implementing Project 2: The Dam Project

The Driving Question

The second project was called "The Dam Project" and sought to answer the driving question: "How much water should we let out of the dam?"

This project began with a discussion of dams and their various purposes. The class was shown the video "Cadillac Desert." After the video, the students read an article on dams. The article was used to help them begin forming their points of view.

One student brought in a video called "The Flood of 93," which the class viewed. The students related their own experiences with floods and how it affected their community. A guest speaker from the Army Corps of Engineers gave a presentation on the multiple uses of dams, and students asked questions.

The Technology

The STELLA™ model for this project gave students control over a virtual water reservoir, with the ability to govern the volume of water which is released from the dam. The release of water affected water levels above and below the dam.

When running the simulation, the student has the power to set the water release rate. Graphical displays indicate the water level in the reservoir, and the relative "happiness" of each of the five special interest groups. While one student from a group had control of the dam for simulation purposes, the others in the group were researching, discussing, or planning.

The Dam Simulation

The Dam Simulation differed from the Easter Island simulation in that it had only one controllable variable – the amount of water released from the simulated dam. The variable was time sensitive over the period of one week, during which time demand for water fluctuated randomly to simulate power needs, weather effects such as rain or drought which affected downstream needs of farmers and upstream needs of recreationists.

The student console (See Figure 5) presented a blank graph on which students would sketch their proposal for water release (See Figure 6). They would then run the simulation accordingly. Sometimes the release rate would match their proposal, and sometimes weather would interfere (not enough or too much water behind the reservoir as a result of rains or drought). The other students in the group would then print off the graphs of their "point of view" and the entire group would debate the proposal seeking a compromise that would be mutually beneficial to every perspective.

Due to students' tendency in the Easter Island project to share their workable solutions, The Dam Project was purposefully constructed so that there was no possible solution to make every member of the team happy.

Figure 5. Student Console, The Dam Project.

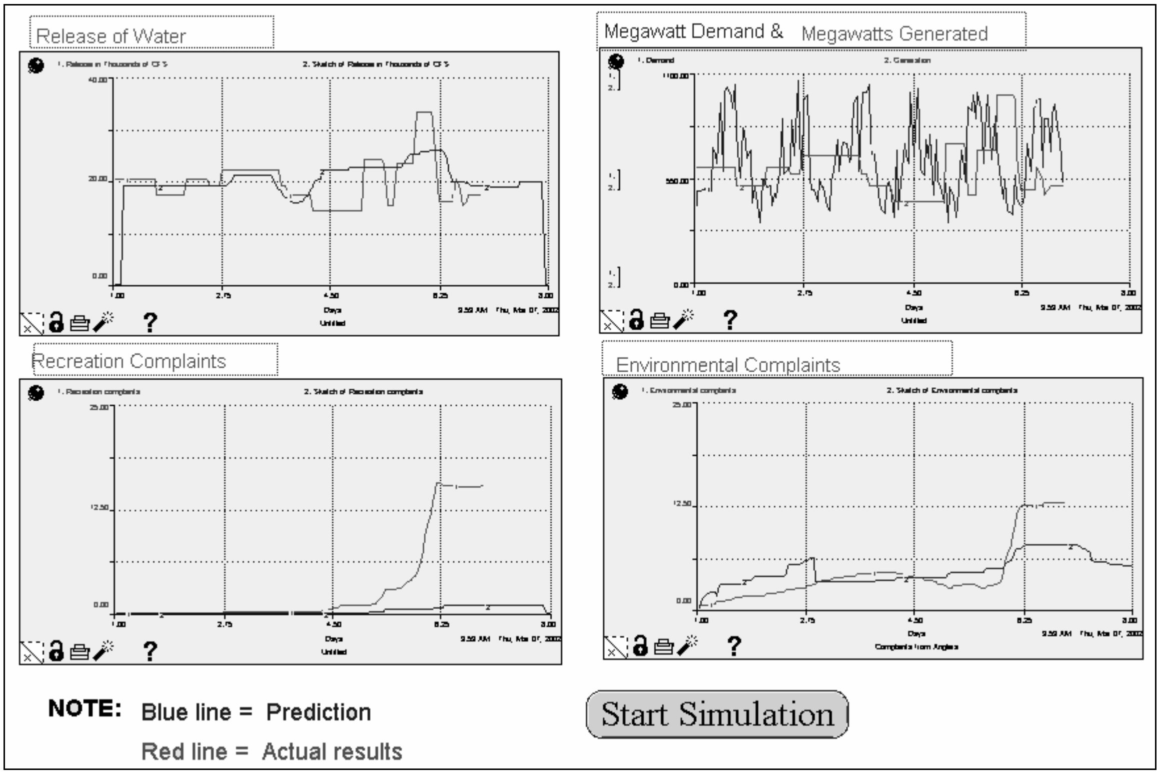
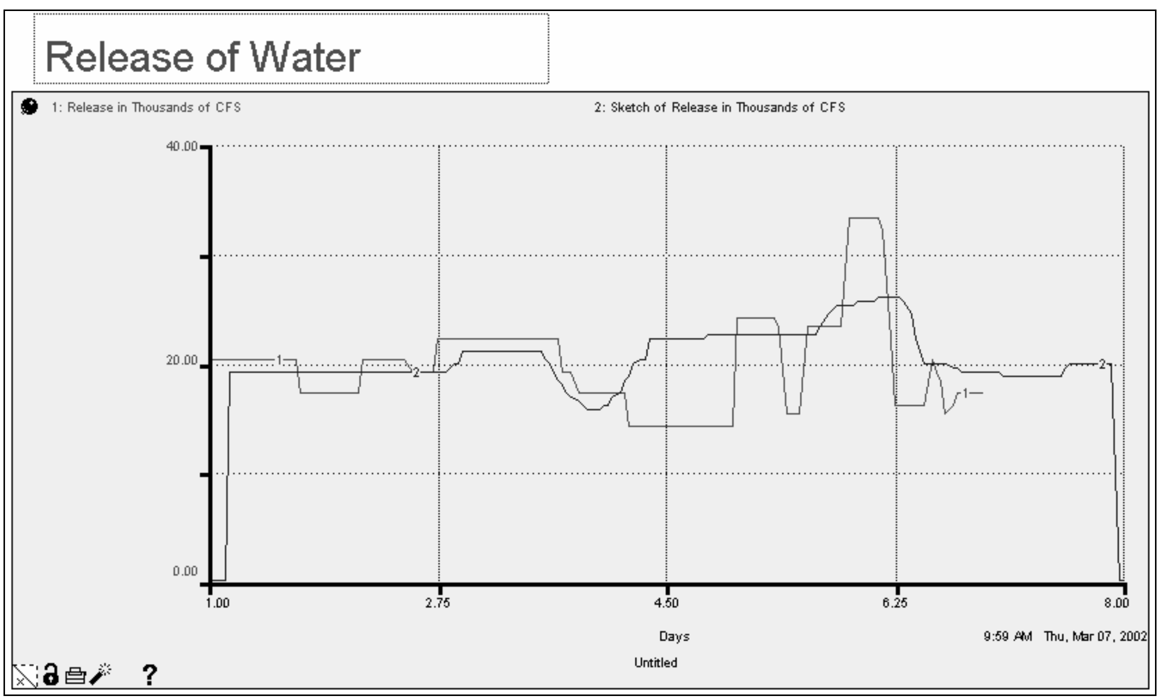


Figure 6. View of student control panel, The Dam Project.



The Community of Inquiry/Collaboration Over Time

Students were placed into five member groups, with an assigned role. The roles were: Conservationists, Recreationists, Farmers, Native Americans and Power Company Personnel (Engineers). The task was to set and justify the amount of water released from the dam based on the specific interests of their role. These interests were:

1. Conservationists are concerned for wildlife and ecology. They want to protect nature and the environment.
2. Recreationists include fishermen, rafters and boaters who want to use the reservoir for recreational purposes.
3. Farmers are concerned about using the water to irrigate their crops.
4. Native Americans are concerned with protecting the surrounding lands.
5. Engineers want to sell electric power generated from the dam.

Initially, students were homogenously grouped by interest. For example, all Engineers were together, as were all Conservationists, etc. This was done to provide commonality among the different roles' points of view. In time, the students began to form heterogeneous groups on their own. Without prompting, they began debating water issues with each other. For this reason, the final groupings were formed such that each group had five members, one representing each point of view.

Because students formed their own groups, and had already begun debating water issues, a list of internet sources was distributed. Students were instructed to first research their point of view, and then reconvene their debate once everyone had some background knowledge. After the second day of debate, students began building their stacks.

The next day, the students were introduced to the simulation. I first modeled its operation, then students were encouraged to "play" with it. When the group members were satisfied they knew how the simulation worked, each member individually manipulated the water flow in the simulation based on their role's interests. The resulting graphs were printed out and brought to the next round-table discussion. Students were instructed to achieve a consensus on how much water should be released. Based on their discussions, students then built a HyperStudio™ stack to explain their point of view, their graph, and their compromises.

The Content Goals

In this project, students were again expected to investigate cause-and-effect relationships between variables in a real-world simulation running in STELLA™. Additionally, students were expected to: make predictions, formulate and analyze decisions and provide convincing arguments from the data displayed in multiple forms. Twenty-three NCTM (2000) benchmarks were selected to represent the mathematical content covered by Project #2 (See Table 30).

Table 30. Content and Concepts covered by the Dam Project..

NCTM Standards and Benchmarks: All students in grades 6-8 should --
Number & Operation • (1.1.1) work flexibly with fractions, decimals, and percents to solve problems; • (1.1.4) understand and use ratios and proportions to represent quantitative relationships; • (1.1.7) develop meaning for integers and represent and compare quantities with them; • (1.3.1) select appropriate methods and tools for computing with fractions and decimals from among mental computation, estimation, calculators or computers, and paper and pencil, depending on the situation, and apply the selected methods; **Algebra** • (2.1.3) identify functions as linear or nonlinear and contrast their properties from tables, graphs, or equations; • (2.2.2) explore relationships between symbolic expressions and graphs of lines, paying particular attention to the meaning of intercept and slope; • (2.3.1) model and solve contextualized problems using various representations, such as graphs, tables, and equations; • (2.4.1) use graphs to analyze the nature of changes in quantities in linear relationships; **Measurement** • (4.1.3) understand, select, and use units of appropriate size and type to measure angles, perimeter, area, surface area, and volume; • (4.2.6) solve simple problems involving rates and derived measurements for such attributes as velocity and density; **Data analysis** • (5.1.2) select, create, and use appropriate graphical representations of data, including histograms, box plots, and scatterplots; **Problem Solving**

- (6.1) build new mathematical knowledge through problem solving;
- (6.2) solve problems that arise in mathematics and in other contexts;
- (6.3) apply and adapt a variety of appropriate strategies to solve problems;
- (6.4) monitor and reflect on the process of mathematical problem solving;

Reasoning and Proof

- (7.2) make and investigate mathematical conjectures;
- (7.3) develop and evaluate mathematical arguments and proofs;

Communication

- (8.1) organize and consolidate their mathematical thinking through communication;
- (8.2) communicate their math thinking coherently and clearly to peers, teachers, and others;
- (8.3) analyze and evaluate the mathematical thinking and strategies of others;

Connections

- (9.3) recognize and apply mathematics in contexts outside of mathematics;

Representation

- (10.1) create and use representations to organize, record, and communicate mathematical ideas;
- (10.2) select, apply, and translate among mathematical representations to solve problems;
- (10.3) use representations to model and interpret physical, social, and math phenomena;

Additionally, students were expected to role-play multiple perspectives, provide justifications for those perspectives, and use graphical representations to support a point of view. Interdisciplinary content themes from social studies and science included resource management, the common good, the role of the public in governmental decisions, and change over time.

Authentic Audience & Reflection

Students were reminded they would be sharing their stacks with an authentic audience of students from another school. Based on their reflections upon the Easter Island stacks, they agreed on the following guidelines:

1. All stacks must have an introduction card.
2. Pictures are needed to support students' ideas.
3. External information must be cited.
4. Do not overuse scrollbars.
5. Avoid putting too much information on a single card.
6. Experiment with different backgrounds and pictures.

Once the stacks were complete, students did an in-class peer evaluation. Constructive comments were collected, reflected upon, and revisions were made based on the results of these reviews. Two representative stacks were then taken to another middle school for review by two seventh-grade classes.

The Teaching

Number & Operation

The Dam Project required students to interpret graphs of quantities which were represented as rational numbers rounded to either the tenths or hundredths place, which meant they had to "work flexibly with fractions, decimals, and percents to solve problems" (SBI 1.1.1). More specifically, each point of view had to propose a rate of flow for water through the simulated dam, and interpret their constituent's complaints in rational form. This means the students would need to "understand and use ratios and proportions to represent quantitative relationships" (SBI 1.1.4) such as the ratio of happy to unhappy farmers given a particular flow of water.

The water flow was determined by a slider, which was calibrated in integer quantities. As students discussed their settings with each other during group time, they would have needed to "develop meaning for integers and represent and compare quantities with them" (SBI 1.1.7), specifically the cubic feet of water released.

As these group discussions progressed, students would propose various settings for the simulation. This discussion involved paper printouts of the proposed settings, on which students would make counter proposals or arguments as to why a given setting would or would not work. This represented their ability to "select appropriate methods and tools for computing with fractions and decimals" (SBI 1.3.1).

Algebra

The NCTM (2000) Standards ask that eighth graders "identify functions as linear or nonlinear and contrast their properties from tables, graphs, or equations" (SBI 2.1.3). The Dam Project exceeded NCTM's (2000) recommendations, as the simulation also generated piecewise and periodic graphs, both of which are high school or above, according to NCTM (2000).

Each time students ran the simulation with their own proposed settings, they were paying attention to the graphical representations of the water flow and the relative happiness of their constituents. In many cases, due to weather effects, the graphical output was piecewise or periodic. In this way, the Dam Project also exceeded NCTM's (2000) recommendation that eighth graders "model and solve contextualized problems using various representations, such as graphs, tables, and equations" (SBI 2.3.1) and to "use graphs to analyze the nature of changes in quantities in linear relationships" (SBI 2.4.1), insofar as the graphs generated by the simulation were more complex than simple linear relationships.

Measurement

The water being released in the simulation was measured in cubic feet per minute. This was a difficult concept for students to grasp initially, but was made concrete by the guest speaker from the Army Corps of Engineers, who brought a one-cubic-foot cardboard box. She explained that one cubic foot per minute was like that box full of water going out of the dam each minute. In this way, she helped students to "understand …and use units of appropriate size and type to measure…volume" (SBI 4.1.3).

After the Army Corps of Engineers speaker explained in concrete terms the idea of cubic feet per minute (CFM), both stacks were able to show evidence that students had understood it. However, Stack A did not explain their understanding of this and other measurement units.

As students worked on their proposals for how much water to release, they were "solv[ing] simple problems involving rates and derived measurements for such attributes as velocity and density" (SBI 4.2.6), in this case CFM (Cubic feet per minute).

Data analysis (student)

Each time students would complete one run of the simulation with their proposed settings, they would print out the graph and bring it back for discussion. Several students also incorporated these graphs into their HyperStudio™ artifacts. In doing so, each student would "select…and use appropriate graphical representations of data, including histograms, box plots, and scatter plots" (SBI 5.2.2), even though piecewise graphs are actually more than NCTM

(2000) recommends for this grade level. Both stacks included examples of these graphical representations.

Problem Solving

The Dam Project tended to involve a form of guess-and-check (NCTM 2000), as it was often unclear what impact the proposed change would have on the other points of view. Students would make a conjecture as to what they thought might happen, but ultimtately the settings just needed to be tried out.

Reasoning and Proof

As mentioned in the Problem Solving section above, students approached the Dam Project as a series of collaborative conjectures. Each point of view would "make and investigate mathematical conjectures" (SBI 7.2) as they related to their own point of view, then reconcile the conjectures with the simulation and the rest of the group.

Communication

The nature of the Dam Project actually forced students to communicate with each other in a mathematical way, as they sought consensus on the settings for the dam. Students had to "organize and consolidate their mathematical thinking through communication" (SBI 8.1), then "communicate their math thinking coherently and clearly to peers" (SBI 8.2). If they were not presenting their findings, they were actively trying to "analyze and evaluate the mathematical thinking and strategies of others" (SBI 8.3) in their group.

Connections

By its very nature, the Dam Project required students to "recognize and apply mathematics in contexts outside of mathematics" (SBI 9.3), specifically the amount of water to release from a simulated dam, and the effect that release would have on others both upstream and downstream from the dam.

Representation

After each run of the simulation, students printed out their graphs and brought them back to the group to discuss. In this way, each student used "representations to organize, record, and communicate mathematical ideas" (SBI 10.1) as they argued for their points of view. Once everyone had experienced this phenomenon themselves, the group would "select, apply, and translate among mathematical representations" (SBI 10.2) to find a solution that would be mutually beneficial to everyone in the group. Since this simulation was about a dam, and how it affected a community, the students were effectively using "representations to model and interpret physical, social, and math phenomena" (SBI 10.3).

Summary of Teaching Issues

Collaboration and Group Roles

The nature of Project 2 required students to come to a consensus about the use of a simulated water reservoir. This presented problems for the students, as this was the first time they had encountered a consensus-building activity. By design, this scenario had no "right" answer, and this was frustrating to the students.

Originally, I had planned to have students manipulate the simulation individually, and bring their results back to the group for discussion. This led to much off-task behavior on the part of the waiting group members. I adjusted the class instructions to allow all members to observe while each member operated the simulation.

Technology & Resources

The class encountered a number of technological problems with this simulation. Often the computer would lock up during a run, and students would have to reboot and lose their settings. As a result, the original time-frame for completion had to be adjusted.

Students again expressed dissatisfaction with the computers, and the crowdedness of the classroom, and the fact that the computers frequently locked up, causing loss of data and time.

The Initial Presentation

A guest speaker from the Army Corps of Engineers was brought in to talk about dams and water management. Students said they were bored, as it was all lecture. They would have preferred more interaction and representation by other perspectives. Students also expressed dislike for the videos shown at the beginning of the project.

Constant Monitoring, Adjustment, and Time

In the Easter Island project, I chose the group members with unsatisfactory results. In this project, group roles were randomly assigned, and groups formed spontaneously. This is an example of monitoring and adjusting project logistics.

The Dam Project was initially designed to run for four weeks, but lasted for six due to the nature of the work being done. The students were deeply engaged and were having highly meaningful conversations, so I made the decision to lengthen the project to allow this high quality work to come to its logical conclusion. In this way I accommodated the students' needs by adjusting the time requirements.

The Learning

Number and Operation

In order for a stack to show evidence of understanding of the first two indicators under number and operation, they would have to describe the rational number quantities reflected in the different point of view graphs, as well as to describe the ratios of unhappiness for each constituent graph. Stack A achieved the second objective, but not the first. Stack B achieved the first objective but not the second.

Both stacks demonstrated evidence of understanding of integers, as both stacks pointed out their solutions in terms of the quantity of water to be released. The remaining indicator under number and operation was also achieved by both stacks, but was observational in nature as groups were observed using computational techniques to arrive at their solution during the simulation.

Algebra

Of the two stacks (Stacks A and B) created in the Dam Project, both showed evidence of understanding of both of the Algebra indicators. To do so, both stacks needed to have a graphical representation of the scenario that incorporated the concept of change over time. This was closely related to the data analysis indicator that required use of an appropriate graphical representation, which both stacks had.

Data Analysis

Even though piecewise graphs are actually more than what were required for this grade level, both stacks included examples of these graphical representations.

Problem Solving

Students seemed to prefer the trial-and-error (or guess-and-check) method as a way to "build new mathematical knowledge through problem solving" (SBI 6.1) as the students tried to "solve problems that arise in mathematics and in other contexts" (SBI 6.2). This finding was based on observational data only, as there was no evidence in the stacks or interviews of their chosen problem solving method.

Guess-and-check was not the only method observed, however. After several attempts at the simulation, some students began to see a pattern in the responses the simulation gave. In this way, students demonstrated their ability to "apply and adapt a variety of appropriate strategies to solve problems" (SBI 6.3) such as guess-and-check and find-a-pattern. This pattern-seeking behavior was evidence that students were "monitor[ing] and reflect[ing] on the process of mathematical problem solving" (SBI 6.4).

Reasoning and Proof

Students quickly became adept at "develop[ing] and evaluat[ing] mathematical arguments and proofs" (SBI 7.3), though the proofs were again informal in nature. This finding was based on observational data, as there was no evidence in the stacks of the group discussions.

Communication

Stack A showed evidence of students presenting their own point of view only, with no regard to other teammate's perspectives. Stack B did include evidence of students writing which discussed other team member perspectives.

The Peer Reviews

Question 1: What were the best features of this stack?

The students who collaboratively created stack A employed a feature of HyperStudio™ that allows rudimentary animation effects. This was identified as the best feature of their stack, with appreciation for their choices for graphics coming in a close second.

The students who collaboratively created stack B employed another feature of HyperStudio™ that allows the embedding of music and recorded sounds. This was identified as the best feature of their stack, with graphics as second best (see Table 31).

Table 31. Peer review responses, Project 2, Question 1.

Category	Stack A	Stack B
Animation	20	0
The overall layout	0	3
Graphics	16	13
Reasoning & discussion	2	6
Sounds	1	16
Slide transitions	1	5
Word choice	1	2

Question #2: Did this group do a good job defending their point of view?

The peer reviewers indicated the group that built stack B had stronger arguments in defense of their points of view. Stack A seemed to have factual errors or weak arguments, as determined by the reviewers (See Table 32).

Table 32. Peer review responses, Project 2, Question 2.

Category	Stack A	Stack B
Strong defense	19	31

Some errors/faults	9	4
Weak arguments	4	1

Question 3: Was the stack easy to navigate/did the navigation make sense?

More reviewers identified Stack B as easier to navigate than Stack A. According to the reviewers, some of the navigation buttons in Stack A did not work, or were confusing in their operation. (See Table 33).

Table 33. Peer review responses, Project 2, Question 3.

Category	Stack A	Stack B
Easy to navigate	20	32
Somewhat confusing	10	3
Confusing/buttons did not work	3	1

Question 4: What mistakes/errors did you find in the stacks?

The reviewers identified mechanical errors (errors in spelling/grammar/punctuation) as the primary error type in stack A, and a significant problem in stack B. In addition, Stack B had many vocabulary words that needed to be defined for their audience. (See Table 34)

Table 34. Peer review responses, Project 2, Question 4.

Category	Stack A	Stack B
Mechanical errors (spelling/grammar)	20	17
No mistakes	12	18
Definitions of new vocabulary needed	3	10
Writing was unclear/confusing	3	2
Run-on sentences	3	2
Graphs need legend/key	2	1

Rubric Results:

In addition to their comments, the peer reviewers were asked to give a score to each of the stacks via a rubric. Stack B consistently out-performed Stack A in all measures on the rubric (See Table 35).

Table 35. Rubric results, Project 2

Category	Stack A	Stack B
Stack Organization	7.3	8.1
Content consistent with point of view	6.5	7.5
Information Quality	7.2	7.9
Spelling and Grammar	5.7	7.1
Interest/Fun/"coolness"	7.1	7.7
Navigation/Buttons	7.4	8.3

The Interviews

As students began finalizing their HyperStudio stacks, groups were selected at random, and individuals from those groups were interviewed. Each group was asked the same set of questions.

Question 1: What did you like about the Dam Project?

Of the students interviewed, the majority indicated they enjoyed the opportunity to defend a point of view. Also students showed high interest in being able to control the simulation and create their stack from their point of view. They indicated enjoyment in being able to express their perspective and to have ownership over their project. Students felt there was better cooperation between partners, compared to Project 1. Several students felt this project was more challenging than Easter Island project (See Table 36).

Table 36. Sample Quotes, Project 2, Question 1.

B2: I liked this one because I'm getting hands-on experience. I get to use the simulation and everything. You get to do your own point of view, how you want it to run, the dam and everything.
B3: It's better than the other one because it's more challenging. You have more objectives to do. In the other project, you just are doing one thing the whole time and it gets boring. But here, you get to keep switching from HyperStudio™ and have to argue and then a whole bunch of other things.
G8: I like being on computers. I'm better on computers than on paper. Otherwise, I would be failing this class.
G13: They are a lot better than worksheets.
G14: Because you get to be not all the same person. In the other we didn't play different parts. In this one we got to talk about different types.

Question 2: Compare "Easter Island" to "The Dam Project"

Of the 15 students interviewed, nine indicated they applied what they learned in the Easter Island (EI) project to their work with the Dam project (DP). Comments indicated they had learned to get the important information first, then move on to creative parts of the project. For six students this was a problem with Easter Island (EI) – that they put too many details and not enough facts into their EI project. In the Dam project (DP), they focused on explaining their point of view more effectively.

Overall, students indicated that their DP stack was superior to their EI stack because, as B6 stated: "Everybody was doing better this time because now we kind of know what we are doing … we are more experienced."

Standards Evaluation

National Council of Teachers of Mathematics standards

Stack B showed evidence of meeting all required NCTM standards for Project 2 with the exception of SBI 1.1.4, which is the use of ratio and proportion. Stack A showed evidence of meeting all standards except SBI 1.1.1, 4.1.3, and 8.3. These standards require work with fractions/decimals/percents, units of measure, and the evaluation of mathematical thinking of others, respectively (See Table 37).

Table 37. NCTM Standards evidence in Project 2 stacks.

NCTM Standards	**S.B.I**	Stack A	Stack B
Numbers	**1.1.1**		X
	1.1.4	X	
	1.1.7	X	X
	1.3.1	X	X
Algebra	**2.1.3**	X	X
	2.2.1	X	X
	2.3.1	X	X
	2.4.1	X	X
Measurement	**4.1.3**		X
	4.2.6	X	X
Data	**5.1.2**	X	X
Problem Solving	**6.1**	X	X
	6.2	X	X
	6.3	X	X
	6.4	X	X
Reasoning and Proof	**7.2**	X	X
	7.3	X	X
Communications	**8.1**	X	X
	8.2	X	X
	8.3		X
Connections	**9.3**	X	X
Representations	**10.1**	X	X
	10.2	X	X
	10.3	X	X

Summary of Learning Issues

Collaboration

Students working on this project had much more success in forming a community of learners. Originally, students were assigned roles, and placed in groups of the same point of view. Students liked having well-defined roles and points of view, which gave them ownership of their part of the project.

In a short period of time, students with opposing viewpoints gravitated to each other and began debating the issues. In this way, (with only minor urging in some cases) students formed very cohesive heterogeneous groups on their own. Students said there was much more cooperation in this project than in Easter Island.

Students were observed frequently assisting each other in critiquing and revising their stacks well before the peer evaluations began. Specifically, students were observed helping with importing graphics, spelling and grammar, animation and sound, and correcting card navigational errors.

Storyboard planning sheets were supplied to the students for "rough drafting" their HyperStudio™ stacks. Since there was a great deal of "down-time" while group members waited for the results from the simulation, many students were observed using the planning sheets to begin sketching out their stacks.

Audience

Students were happier with an outside peer review (outside of their school), as they felt the comments were more trustworthy. They felt that they could tell their explanations were "good enough" for peer reviewers to understand.

The goal of presenting to an authentic audience proved to be highly motivating. Students exhibited urgency in finishing their projects on time. After the peer review, the student took the recommendations of the reviewers seriously, and made many improvements, such as:

1) Fixing spelling, grammar, and readability errors.
2) Adding technology aspects such as narration, sound, graphics, and animation.
3) Eliminating large sections of text in favor of diagrams.
4) Eliminating "jargon"

The Scenario

Students did not like the fact that this project did not have a "right" answer, and that they were forced to come to a compromise that did not have a clear benefit. In comparison to Easter Island, students said this scenario was more real-life to them, since it was something that could take place today whereas Easter Island took place in the past.

Technology

Students commented that they lost too much time hunting for graphics and sound, and that next time they would concentrate on getting the information first.

While students reported enjoying working in groups, they felt the limited technology prevented them from realizing this projects full potential. They requested that each person should have their own computer for the next project.

Experience

Students expressed feeling more "experienced" in doing this sort of project, thanks to Easter Island, and were more comfortable with what was expected of them. Students asserted that they learned from the mistakes they made in the last project.

Implementing Project 3: The City of the Future

The "Driving Question"

In the third and final project, students were required to answer the question "How can you design a city which is powered entirely from renewable energy sources?"

The Content Goals

The content goals for "City of the Future" were to have students take measurements made on a local (home) scale and extrapolate them to a larger (city-wide) context. This would require the use of change-of-scale techniques, tabulation of data, and estimation within a frame of reference.

In accordance with NCTM Goal 1 (Learning with understanding), ten content and instructional mathematics standards were selected from NCTM (2000) (See Table 38).

Table 38. Content and Concepts covered by the City of the Future project.

NCTM Standards and Benchmarks: All students in grades 6-8 should --
Number and Operation • (1.1.7) Develop meaning for integers and represent and compare quantities with them. • (1.3.1) Select appropriate method and tools for computing with fractions and decimals from among mental computation, estimation, calculators or computers, and paper and pencil, depending on the situation, and apply the selected methods. **Algebra** • (2.3.1) Model and solve contextualized problems using various representations, such as graphs, tables, and equations. **Measurement** • (4.1.2) Understand relationships among units and convert from one unit to another within the same system. • (4.2.1) Use common benchmarks to select appropriate methods for estimating measurements. **Problem Solving** • (6.1) Build new mathematical knowledge through problem solving **Communications** • (8.1) Organize and consolidate their mathematical thinking through communication • (8.2) Communicate mathematical thinking coherently & clearly to peers, teachers, and others; • (8.3) Analyze and evaluate the mathematical thinking and strategies of others; **Representations** • (10.1) Create and use representations to organize, record, and communicate mathematical ideas.

The Technology Tools

Students watched three short video programs about energy, electricity, and power generation, to provide background information to start the project. After each segment, I led an oral discussion around the information presented in the video. The students were then asked to conduct an energy survey of their own homes. They were to create a detailed list of all electrical appliances in their home, the length of time the appliance ran on a given day, and the wattage of each appliance. I provided details on how to safely find this information, and encouraged students to ask parents or other adults for help when necessary. The following class period was spent creating a master list of appliances, and their energy usage. This master spreadsheet was shared with all participants as a basis from which to build their city's energy budget (See Figure 7).

Figure 7. Sample Energy Budget, Project 3.

	A	B	C	D	E
1	**Appliance**		**Wattage**		**Time**
2	lighted mirror		23 watts		1 hour
3	radio		4 watts		18 hours
4	lamp		100 watts		4 hours
5	alarm clock		5 watts		24 hours
6	clock		5 watts		24 hours
7	fan		35 watts		18 hours
8	radio		7 watts		16 hours
9	phone		9 watts		24 hours
10	t.v		120 watts		10 hours
11	radio		7 watts		14 hours
12	stereo		14 watts		3 hours
13	phone		9 watts		24 hours
14	toaster		900 watts		1 hour
15	coffee pot		1200 watts		5 hours
16	refrigerator		120 watts		24 hours
17	stove		3000 watts		5 hours
18	microwave		1020 watts		1 hour
19	light bulb		100 watts		12 hours
20	vcr		14 watts		5 hours
21	dvd		30 watts		6 hours
22	play station		19 watts		2 hours
23	freazer		575 watts		24 hours
24	washer		82 watts		15 hours
25	dryer		6720 watts		15 hours
26	culling iron		22 watts		1 hour

Table 39 shows the initial project information students were then presented with as the "Requirements for the City of the Future":

Table 39. Requirements for the City of the Future.

The State Legislature has set aside a budget grant for the creation of a city which is to be run entirely on alternative energy sources. The state has set aside an entire county for the creation of this city. The city will become the county seat, and as such will have the responsibility for municipalities for the county. As city planners, you must accommodate the following ***MINIMUM*** requirements: • Housing for 3000 ***families*** • Elementary, Middle, and High Schools • 2 Laundromats • 7 restaurants • 4-plex theatre • 5 gas stations • A County Courthouse (100 offices, 10 jail cells, Auditorium, Police and Fire station) In addition, you should make such plans as are necessary to accommodate city growth over time. Things to consider: · Are there street lights in your city? · Where are the energy sources located in your city? · How are the streets laid out in your city? · Are there parks/recreation facilities in your city

Students decided what appliances would be needed for each building in their city, and how long they would be used. From that information, they calculated the total energy needed for their city. They then researched the renewable energy sources available to their city based on the geographic location of their city, and how much energy could be generated from them. If there was a shortfall of energy, students had to find a way to adjust their budget, or implement rules and laws to help throttle the energy used by their city.

Finally, student used SimCity™ 2000 to develop a map of their city, complete with geographic land forms (hills, mountains, rivers, etc.) which they used as a visual for their HyperStudio™ advertisement of their city.

A new computer lab was made available to the class at this time. It had 25 Pentium-class networked computers. This made a computer available for each student. I provided an example stack to demonstrate the expectations for the project. Students were then introduced to the simulation and allowed time to "play" with it. After one class period students were expected to begin working on their projects. Students were once again told to design their HyperStudio™ stacks to be viewed by an authentic audience.

Each student drew the name of a state out of a hat. This state was the location of their city. Students were allowed to negotiate trades of states with others in the room. The students then used the Internet to locate maps and details of the resources available in their given states. Students were limited to using only the kinds of energy sources as would normally be found in their state (for example, a student could not use tidal energy if they had a land-locked state such as Kansas). Students were given minimum requirements for their city (See Table 39), and were told they were free to meet these requirements in any reasonable way, including the use of rules and laws.

Due to end-of-year activities (fieldtrips, concerts, sports, etc.), several students were frequently absent from class during this project. Because of these absences, some students were unable to complete the project. Those students' stacks were not evaluated.

The Teaching

Number and Operation

The City of the Future project started out with a data-gathering activity, in which students created a common spreadsheet composed of household appliance wattages and the duration each was operated. Most appliance labels list their wattage as integer values. As they built their spreadsheet and compared the wattages of appliances in their homes, students were "develop[ing] meaning for integers and represent[ing] and compare[ing] quantities with them" (SBI 1.1.7).

By building the spreadsheet, students were demonstrating that they could "select appropriate methods and tools for computing with fractions and decimals from among mental computation, estimation, calculators or computers, and paper and pencil, depending on the situation, and apply the selected methods" (SBI 1.3.1), the fractions and decimals in this case refer to the duration of time (such a half-hour equating to 0.5, or ½).

Algebra and Representations

The City of the Future project required students to "create and use representations to organize, record, and communicate mathematical ideas" (SBI 10.3). In this case, the representation was a spreadsheet which students used to keep track of a master list of energy values.

Measurement

Computing the energy needs for an entire city involved very large numbers, as students quickly noticed, when computing in wattages. Students could decide to convert their answers to kilowatts or megawatts to simplify their computations. This would demonstrate that they "understand relationships among units and convert from one unit to another within the same system" (SBI 4.1.2), in this case metric energy units.

Problem Solving

Students began the City of the Future without understanding how much energy a city would need, nor how much energy was available from renewable resources. Once they began computing the needs and resources available for their city, students began to seek other ways to compensate for the energy shortfall. Some chose to use multiple energy sources, others implemented laws to control energy usage. In this way, students "build new mathematical knowledge through problem solving" (SBI 6.1), especially when considering which energy sources would be intermittent, and which would be constant.

Communications

The HyperStudio™ artifact for this project was an advertisement for the City of the Future that each student built. Students had to pull together their energy budget, their energy source(s), and any strategies they had come up with for their city governance. They then had to write it all up in a persuasive manner to "sell" their city to potential residents. In this way the students "organize[d] and consolidate[d] their mathematical thinking through communication" (SBI 8.1). The advertisement itself was a way to "communicate mathematical thinking coherently & clearly to peers, teachers, and others" (SBI 8.2).

Summary of Teaching Issues

Time

Time was the single most problematic factor, as this project was not started until approximately one month prior to the end of the school year. This timing was less than ideal, as many students were absent due to other class projects, field trips, and end-of-year activities. As a result, only 75% of the students actually finished their projects. Students commented that this project would have been the "best yet" if only they had more time.

Technology

Having up-to-date technology made the project much easier, but also eliminated much of the collaboration that had occurred in the cramped classroom setting. Newer and faster computers did not necessarily make for better artifacts.

The Learning

Number and Operation

All stacks except G13 included their city's spreadsheet representation of the energy budget for their city, and an explanation. Stack G13 did not include a spreadsheet. It may be the case that this stack was unfinished, which would explain why this critical piece was missing.

Algebra

Students quickly learned how to use the spreadsheet to build their own energy budgets. Students discovered they could use simple equations in the form of spreadsheet formulas to do the computations for them. In this way, students learned how to "model and solve contextualized problems using various representations, such as graphs, tables, and equations"

(SBI 2.3.1). With the exception of G13 and G6, all stacks included a spreadsheet model. In all fairness, these two stacks may not have been finished by the time they were evaluated.

Measurement

Several students chose to stay with kilowatts, since they noted their parents' energy bills were in kilowatt-hour units. This is a demonstration of using "common benchmarks to select appropriate methods for estimating measurements" (SBI 4.2.1).

Based on their stacks, this was an especially difficult set of outcomes to understand. Stacks G3, B7, G9, and G15 did show conversions from watts to kilo- or Mega-watts. Stacks B4, G5, G7, G8, G10, G11, and G13 chose not to convert (leaving everything in terms of watts), and so there is no evidence that they understand converting measurements. Stack G6 did not convert correctly, and did not use a common benchmark measurement, frequently switching from watts to kilowatts.

Problem Solving

All stacks except G6 explained their solution to the energy shortcomings of the various sources. Stack G6 may not have been completely finished, which might explain why it was lacking in this area.

Communication

All stacks except G6 showed evidence of meeting these goals through their discussions of the energy needs, their energy source, and solutions to cope with shortfalls.

Throughout this project, students had to find information on cutting-edge renewable energy resources. Considerable time was spent evaluating internet sources for credibility and quality of information. In this way, students "analyze[d] and evaluate[d] the mathematical thinking…of others" (SBI 8.3), especially when it came to claims of how much energy a renewable source could provide (See Table 40).

Table 40. Sample comments from students evaluating internet information.

G14: yeah most of the time it's ok … sometimes you go to one site and you hear one thing and go to another site and it's another thing. Like which one?

G11: You go to a site that …looks like it's been built by a lot of people then it seems reliable to me.

B4: …if there is a bunch of things[websites] that say about the same thing and they all mentioned that they are close to the same answer then yeah.

G13: they way it is told, like if it is more professional like the way they type it, the way it is type you can tell but it you compare two, one would like really messy and using slang and stuff the other would be like sound like it is right out of the dictionary.

National Council of Teachers of Mathematics Standards

Stacks B7, G15, G3 and G9 were the only stacks meeting Measurement-Attributes-2, which asks students to convert measurement units. Stack G13 did not meet either of the Numbers indicators, the Algebra indicator, or Measurement-Attributes-2. Stack G6 did not meet any of the Measurement indicators, the Problems Solving indicator, or either of the Communications indicators (See Table 41)

Table 41 - NCTM Standards, Project 3.

Standards	**S.B.I**	B4	B7	G10	G11	G13	G15	G3	G5	G6	G7	G8	G9
Numbers	**1.1.7**	X	X	X	X		X	X	X	X	X	X	X
	1.3.1	X	X	X	X		X	X	X	X	X	X	X
Algebra	**2.3.1**	X	X	X	X		X	X	X	X	X	X	X
Measurement	**4.1.2**		X				X	X					X
	4.2.1	X	X	X	X	X	X	X	X		X	X	X
Problem Solving	**6.1**	X	X	X	X	X	X	X	X		X	X	X
Communications	**8.1**	X	X	X	X	X	X	X	X		X	X	X
	8.2	X	X	X	X	X	X	X	X		X	X	X
	8.3	X	X	X	X	X	X	X	X		X	X	X
Representations	**10.1**	X	X	X	X	X	X	X	X		X	X	X

Interviews

As the final project drew to a close, students were interviewed in pairs about the final project, and the whole year's worth of project-based lessons.

Question 1: Which project did you think was the best?

A majority of the students interviewed thought the third project was the best. The primary reason expressed was that students felt the most ownership and control, as they designed their own city. The second most prevalent reason was that students felt the most comfortable with the technology and software by the end of the third project. Two interviewees indicated the second project was the best due to the collaborative nature of the project, and that they had more time to work on it .

Table 42. Sample quotes, Question 1, project 3.

B4: We had time, we had cooperation and we actually had time to think it through what we actually were doing. This one we were kind of in a rush. The first one we barely got to know the project and what we were doing. By the middle we had a clue to what we were doing.
G3: It's fun, you are like making your own city.
G5: We actually get to build something.
G9: It's everything how we want it. I know I can't always have what I want but this is as close as it gets.
G11: I liked the Dam project because we had a guest speaker and everything.

Question 2: Which stack do you feel was your best?

The majority of students felt the City of the Future stack was their best work. They stated the reason was that this project gave them the most freedom to create and design. Students also stated that having a computer all to themselves made the project better. Additionally, students stressed that for this project they felt more comfortable with project-based learning, the software, and technology (See Table 43-45).

Table 43. Which stack do you feel was your best?

Student Comments	Number of Responses
City of the Future	9
The Dam Project	2
Both Dam and COF	2
Don't know	1

Table 44. Sample quotes regarding why COF was their best stack

B5: Yeah, because I've learned how things work. I can do more sounds and stuff. It gets done faster and improves each time. B8: Yeah, you design your own city and make up your own laws and stuff. G3: This one you had your own information. You are making your own town…it's better. G14: It's like building your own little model. You put what you want in there. However much of this and that and in STELLA you almost think that you are limited because of the graph and stuff because you have to get it in an area. It's got to be like this. [You] gave us some requirements for our city but that doesn't keep us from adding more. G15: It seems like we have more information than we did before any other one because really when we did the other ones we were not too sure what to put in them. So this one pretty much we knew because we created our own city.

Table 45. Sample quotes regarding why the Dam project was their best stack.

G11: I liked the Dam project because we had a speaker and everything. B4: We had time. We had cooperation and we actually had time to think through what we were doing. This one we were kind of in a rush. The first one we barely getting to know the project and what we were doing. By the middle we had a clue to what we were doing.

Question 3: What project did you like the least?

Students liked the Easter Island project the least. A majority of students indicated they felt overwhelmed with facts and not enough freedom to create. They felt the scenario was not realistic. The students indicated they wanted more real-life situations dealing with real-world problems. Since EI was a historical scenario, they did not feel that it represented a real-life situation.

Four students liked the Dam project the least. These students claimed it had too many objectives. Students also indicated they did not like being required to form a group consensus about water levels (see Table 46).

Table 46. Sample quotes responding to "What project you liked least?"

B6: I think it was the Dam project because it was like so hard to get stuff done. There were too many people in our group first of all, and second of all, there was like so many different objectives and like you had to get your stack done and you had to do the dam raising of the water and the electricity and keeping everybody happy. It was just harder I think. G13: I didn't like the Rapa Nui because we had to go back in time. G14: It was too much fact. You want some fiction in there you know where you can make up your own thing.

Summary of Learning Issues

Time

Time was an inhibiting factor for the students. They felt this could have been their best stack, had they more time to work on it. The City of the Future project was started one month prior to the end of school, and students were involved in numerous activities which took them out of class periodically. Since the end of school was a firm deadline, I was not able to adjust the end-date of the project. As a result, many students did not finish their stacks.

Collaboration

After doing so many projects, students had formed a very cohesive community of learners as a whole class, as evidenced by the amount of assistance and advice being exchanged during work sessions. Students who knew how to use SimCity 2000™ assisted those who did not, and many students shared internet site addresses with each other. While this project did not require a peer evaluation, students were observed having their classmates proofread their stacks for them.

Students showed a high level of interest in alternative energy and found information about resources that they ended up not using, but discussed with each other. By collecting the energy data and collaboratively building the energy spreadsheet, students appeared to have a better appreciation for energy use not only in their homes, but on a larger scale. Students expressed amazement at how little energy could be extracted by windmills and solar panels, when compared to the energy used by a whole city.

CHAPTER 5 - Themes and Recommendations

In Chapter 4, I provided a thick description of the three projects described in this study. Issues relating to implementation of these projects were detailed. An analysis of the teaching process was described, including the content goals for each project and a description of the mathematics necessary to successfully operate each simulation. Student learning was outlined, with analyses of peer review data, summary of interviews, and a correlation to the learning outcomes.

In this chapter, I answer my research questions by describing several themes which emerged with respect to teaching and learning mathematics in a PBL-based environment. I also provide several recommendations for teachers wishing to implement a similar environment in their own classrooms, and suggestions for future research.

Goal of the Study

The goal of this study is to explore the use of interdisciplinary PBL projects for teaching mathematical concepts according to NCTM (2000) goals for mathematics instruction. These projects involved students in using the STELLA™ and other dynamic modeling software. My initial guiding question was: What are the teaching issues and evidence of student learning of mathematical concepts over a series of three interdisciplinary PBL projects involving STELLA™ modeling software which are designed to engage students, integrate technology, and provide a context for learning mathematics based on the 5 NCTM (2000) goals?

The data gathered in this study were characterized as belonging to two variable clusters: teaching, and learning. Two sub-questions were developed relating to the two variable clusters:

1) What are the issues related to teaching mathematics concepts in a technology-rich, interdisciplinary PBL project which follows the 5 NCTM (2000) goals?
2) What are the issues related to learning mathematics concepts in a technology-rich, interdisciplinary PBL project?

Answering the Research Questions

My initial question was: "What are the teaching issues and evidence of student learning of mathematical concepts over a series of three interdisciplinary PBL projects involving STELLA™ modeling software which are designed to engage students, integrate technology, and provide a context for learning mathematics based on the 5 NCTM (2000) goals?"

The goals of PBL and the 5 NCTM(2000) goals worked together to form a framework which enabled students to achieve a high level of success in coming to understand the selected mathematical concepts for each of the three projects.

The driving questions from PBL were a framework upon which standards-based projects were designed. These projects with their accompanying standards promoted NCTM's goal of learning with understanding by providing real-world, authentic, ill-structured problems to solve.

Both PBL and NCTM's goals call for collaboration, and students did indeed collaborate. Though they initially balked at the formation of a community of learners, the students did finally achieve it through the honoring of diversity and much flexibility on the part of teacher and students. In this community of learners, the students successfully collaborated on projects that lasted from a month to six weeks in length.

Both PBL and NCTM call for technology integration for the sake of learning and communicating. Students utilized STELLA™ simulations, spreadsheets, and SimCity™ as learning tools. HyperStudio™ allowed students a creative and fun way to communicate.

Student-generated artifacts to be presented and evaluated by authentic audiences, as per PBL's goals. Feedback from these audiences led students to critically reflect on their artifacts and to make revisions and improvements as suggested by NCTM's goals.

Data gathered from the three projects were categorized two ways: 1) Teaching – what happened during the projects; 2) Learning – what evidence was found for learning of concepts. In the following sections I will describe the themes that emerged from my analysis of teaching, and the evidence that indicates students learned the selected mathematics concepts.

Teaching: Summary of Findings

After examining the data, several themes suggest themselves–themes which interrelate the issues surrounding PBL, technology integration, and the teaching of mathematics. These themes are:

1) Collaboration on a meaningful, group-worthy topic.
2) Relevance and Engagement.
3) Creativity, Ownership, and Freedom
4) Critical review & reflection
5) Constant monitoring, adjustment, and time

Collaboration on a Meaningful, Group-Worthy Topic.

At the outset of this investigation, I was determined that students would collaborate on all three projects in some way. It was my desire that they should form a "community of learners" and to that end I had initially decided to form 2-person teams for project 1. As the classroom teacher, early in the school year I formed pairs of students by selecting names randomly. This proved to be unfeasible as personality conflicts immediately erupted within several of the groups. I attempted to alleviate this by disbanding and reforming the groups. This also proved inadequate. In order to proceed with the investigation, I allowed several individuals to work alone. This did not prove to be as much of a problem as I had originally thought, however. The first project proved not to be group-worthy.

The Dam Project is an example of a group-worthy project. From the beginning, students had roles assigned to them (recreationist, conservationist, Native American, engineer, farmer). These roles gave structure to their interactions with each other in a collaborative group, as well as their interactions with the simulation, and ultimately their artifacts. After assigning roles, I provided time for research and collaboration among other students assuming the same role. This was done so that the individual students could form a coherent perspective for their role.

Within a few class periods, a fascinating situation became apparent. Students with opposing points of view began forming impromptu groups on their own. Without any prompting from me, students began debating with each other over the issues relating to the use of water reservoirs. I allowed this to continue until a logical break presented itself, and at that point I introduced the self-designed groups to the simulation and presented the driving question.

Unlike the first project, there were no group-dynamic issues. Nobody asked to work alone. There was friction within the groups, admittedly, but that friction was based almost entirely upon the assumed roles for the project, and only reflected the natural friction between the perspectives. Students were frequently observed asking each other to proofread and critique their artifacts, and took their suggestions to heart by making substantial edits.

The final project, "City of the Future" was a different sort of group-worthy project. Unlike The Dam Project, students did not interact with each other to operate the simulation or to create their artifacts. Instead, the collaboration finally took on the desired "community of learners" I had sought. Students collaborated as a whole class to create a living document (spreadsheet) which held an ever-growing list of household appliances and the wattage they used. Students were observed frequently helping each other to calculate the total energy used by a business, as required by the project. Students who were quite facile with the software were observed taking time away from their own work to help others resolve a problem, or suggest other approaches or resources they might use. As in The Dam Project, students asked each other to critique and proofread their artifacts, and took their peers' suggestions to heart.

Relevance and Engagement

The first project, Easter Island, was not intended to be the first PBL project. A scenario called "Attack of the Killer Mosquito" which involved triage and treatment of a simulated injured human being was abandoned shortly before the start of the project in early October of 2001. In September of 2001, terrorists destroyed the World Trade Center in New York. The Principal of the school suggested (and I agreed) that perhaps this first project would be inappropriate, since the nature of the project may have been disturbing in light of 9/11.

As a replacement scenario, Easter Island proved to be less than adequate. While I attempted to make connections between the simulation of Easter Island and resource depletion by comparing it to the California energy crisis, students expressed that trying to prevent a population "meltdown" in the past did not have enough relevance to them.

The Dam Project seemed much more engaging to students. A primary reason for this was that the scenario was much more relevant to the students, and much more realistic. Students in this study lived in a community which had several water reservoirs nearby, which made the scenario immediately applicable to their daily lives.

The final project, "City of the Future" also seemed more engaging than Easter Island. Students expressed in this project, as in The Dam Project, that the scenario had relevance to their daily lives, and was immediately applicable to their own personal experiences.

Issues surrounding engagement came to the fore very quickly with the Easter Island project. In its original form, the simulation presented a 600-year time span on the island, and required manipulation of variables such as birth rates, resource management, disease, and the impact of other outside influences. It quickly became apparent that this was too complex for the students to grasp for their first project, so the number of impacting variables was cut down. This rendered the scenario rather "boring" according to students. The interactions with the simulation had become tedious, as it was now simply trial and error – plug in one set of values, run the simulation, check the result, repeat. One student commented:

> "I think it's ok but it gets kind of boring cuz we keep doing the same thing, know your trying to get us to learn it and all but we are doing the same thing like word fractions and those type of things."

Eventually, as a few groups found a set of values that ended in a workable solution, that solution quickly became the only solution. This problem did not occur in the other two projects, partly due to the nature of the project, but mostly due to the engaging nature of the scenarios. The Dam Project allowed for collaboration as well as individual expression, which was good, as another student commented:

> "In the first project I didn't really do too much [my partner] did most of it. I was just watching and really didn't know what I was doing. But this time since we had to do a stack of our own like explaining why we didn't want it or why we did want it and when I did that I was able to do it more …I understood it."

Creativity, Ownership, and Freedom

Students in all three projects utilized HyperStudio™ to create multimedia artifacts of their understanding for each of the three projects in this study. The majority of students expressed a positive response toward using HyperStudio™ to create learning artifacts throughout each of the three projects. Students also expressed that creating artifacts via HyperStudio™

actually helped them to understand the STELLA™ simulations. While this perspective was not universal, it did represent a majority of responses.

In the first project, I had noticed that students were having difficulty expressing in words their understanding of what graphs and tables meant. I asked T-2 to help students overcome this problem. While in many cases this proved to be a worthwhile intervention, some students felt it had become a barrier to creativity. Students complained that with the extra structure T-2 required, that their stacks were starting to look the same, and that they no longer felt ownership of their story.

In the second project, students expressed how much more positive the experience was as a result of having a role within their groups. This role allowed them to own a perspective, and internalize it enough to have meaningful dialogue, form mathematical arguments, and constructively debate perspectives on the way to forming consensus.

In the third project, creativity, ownership and freedom took on a new form as each student created their own virtual city run by renewable power sources. The students expressed that this was the best project, in terms of how much freedom and control they had in meeting the requirements of this project. Had they not run out of time, I also believe it would have been the best set of artifacts for this very reason.

Authentic Audience

The first time students' work was presented to an authentic audience, students were uneasy with the process, and were observed expressing dismay and unhappiness with the critiques provided by the audience. This was, apparently, the first time they had experienced such a process. Several students actually asked to observe as audience members did their critique. When, on all three projects, they received the comments from the review, many were observed verbalizing their responses to the criticism. These responses had traction, apparently, and it was gratifying to see that students took the critiques to heart and made substantial changes to their work to improve and correct their artifacts as per the suggestions of their reviewers.

In subsequent projects, students were observed asking each other to proofread and critique each other's work in advance of the presentation to an authentic audience. In this way, it is clear the authentic audience had raised their level of concern for the quality of their artifacts.

Critical Review and Reflection

Perhaps the single most impactful activity across all three projects was the review of student artifacts by others, and the subsequent reflection and revision by students. Each project was subjected to review by other classes and in some cases other schools. While this was initially an uncomfortable situation for students, the results were remarkable.

Subsequent reviews went much more smoothly, and students began to ask each other to proofread and critique their artifacts in advance of the reviews. Most prevalent among the issues being corrected were mechanical errors (spelling and grammar). Students also acknowledged the need to get the required information ("stuff") in place before worrying about clipart, sounds, and other "fluff." Even so, the reviewers showed marked interest in well-placed graphics, sounds, and animation.

Constant Monitoring, Adjustment, and Time

Early in the Easter Island project, it became clear that students were having difficulty coping with the complexity of the simulation. Because of this, the first project was pared down into three smaller, less complex sub projects. Extra feedback was given in the form of notes from the Chief of the Rapa Nui, in order to help students to recognize how they needed to proceed. Easter Island was initially scheduled to take three weeks of time, but needed six. These are examples of how critical it was to constantly monitor the progress of students, and to make adjustments to the nature of the project.

The Dam project was also designed to take three weeks, and took six. As the teacher I observed a high degree of engagement, thoughtful dialogue, and quality mathematical instruction taking place and wanted to prolong it to a logical conclusion. To have ended the project early would have robbed it of much of its instructional power. An example of this is the third and final project.

City of the Future began one month prior to the end of the school year. There was no opportunity to extend the time on this project, and the student artifacts clearly showed the students did not have time enough to bring the project to a firm closure (See Table 41). Students were dismayed at the lack of time as well, stating that this could have been the best project but for the lack of time.

In all instances, the role of the teacher is as an active monitor of student progress. PBL projects such as these require diligence on the part of the teacher to make adjustments to the project, provide feedback to redirect students whose work begins to stray, and to adjust the time requirements both to lengthen a project when good learning is taking place, and to shorten it when learning begins to stagnate.

Learning: Summary of Findings

After examining the data, I found that several themes suggested themselves–themes which interrelate the issues surrounding PBL, technology integration, and the learning of mathematics. These themes are:

The content

The conflict between creativity and content

Engagement in a worthwhile endeavor

Learning to express mathematical thinking

The Content

Overall, students who successfully completed all three projects did so in such a way that they met, and in some cases exceeded, the content goals set for the projects. The notable exception is the final project, which most students either did not finish or did not finish well. I consider that to be a fault of the timing of the third project as I described in the implementation issues section of Chapter 4.

In terms of the necessary math content, the vast majority of stacks were successful in accomplishing the conceptual goals set for them. Notably, some students had difficulty working with representations of numbers. In a few cases, students refused to use rational number representations of data, and did not use conversions within measurement systems. This may be due to the fact that these aspects of math were was not as interesting and engaging as working with graphs or arguing from a point of view. It may also be that the students did not have a firm grasp of the use of those concepts and were uncomfortable in using them.

Many of the students expressed in interview or to me during casual conversation that these projects did not feel like they were doing math. To them, based on comments and observations, math is what you do on a worksheet or out of a book. This led to some consternation until they realized at the end of the first project that they probably knew more about word problems and explaining graphs than their contemporaries in other classrooms (See interview sections of Chapter 4). That seemed to make them feel some measure of pride, especially when they began to grapple with the feedback from reviewers.

It seems clear that PBL-based activities lend themselves well to incorporating content standards for conceptual understanding. It is my opinion that had these projects been truly interdisciplinary, in the sense that all content area teachers were involved throughout, the results may have been even more powerful. In the appendices, I include an examination of the content goals that could have been implemented through these projects, and an examination of the evidence of other content standards that students met.

I conclude that there is evidence of students learning mathematics concepts in the course of these three projects. In many cases the concepts exceeded my expectations. While I acknowledge that not every student or group of students met every standard every time, there is evidence to suggest that the highly engaging nature of these projects would have allowed students the opportunity to fill in their conceptual "holes" if only given enough time and feedback. This confirms Boaler's (2006) work on the power of PBL in the mathematics classroom.

The Conflict Between Creativity and Content

Across all three scenarios, students were eager to get through the simulation part of the project in order to do the creative and "fun" part of the project – the HyperStudio™ stacks. In the first project, many students got caught up in the "fluff" of transition effects, looking for graphics and sounds, and other creative aspects. As a result, those same students found themselves considerably behind the other students as the deadline approached. In interviews, students expressed that they had learned they needed to put the "stuff" of the content ahead of the "fluff" of creativity.

It should be noted, however, that the more creative students apparently knew what they were doing with respect to their intended audience. A majority of peer reviewers valued the "fluff" highly, giving high marks to stacks that had fun and interesting approaches to their presentation. That is not to say that content was not important, as many of the stacks that rated highly on creativity were also rated low on such things as explanations of their graphs and points of view.

Engagement in a Worthwhile Endeavor.

I freely acknowledge in the teaching aspects section that the first scenario was perhaps not the best scenario with which to introduce students to technology-based PBL. Students quickly became bored with the scenario, ultimately resorting to what could be considered as cheating to finish the simulation portion of the project. Many students expressed displeasure through interview quotes and observations. This lack of enthusiasm for the project may have contributed to the collaboration issues described in the implementation section of project 1 in Chapter 4.

The second and third project scenarios were apparently more engaging and worthwhile to the students, as there were markedly fewer engagement and boredom issues. This may be due, at least in part, to the fact that students felt they knew more of what was expected of them in this sort of PBL-environment, as evidenced by observation and interview quotes.

Learning to Express Mathematical Thinking

If this study were allowed only one significant success, it would have to be the improvement students showed in expressing themselves mathematically. As detailed in the implementation section for project 1 in Chapter 4, the first project was fraught with difficulties in getting students to explain the graphical results of their simulations in written form. A fellow teacher was brought in as an intervention, and except for complaints about loss of creativity the intervention seemed to work.

Initially, students were uneasy with the feedback they were getting from peer reviewers. They felt like the reviewers couldn't accurately judge the merits of their work since the reviewers didn't know what the authors knew about the subject. That was a turning point for them – realizing that they needed to explain their understanding to the audience.

The second project elicited no such difficulties in explaining the output of the simulation. In fact, the students expressed that defending their points of view was one of the highlights of the second project. This is significant for the second project especially since observationally the second project seemed to cause the most internal strife due to the necessity of coming to consensus, and the fact that the simulation actually had no solution. Nevertheless, students persisted, and found ways to compromise with each other, often arriving at a solution that made everyone equally unhappy. For eighth graders, this is a remarkable achievement.

Summary and Epilogue

Through the course of three interdisciplinary projects, students found that project-based mathematics was unlike traditional mathematics classes. Students found they could incorporate technology, creativity, and collaboration into learning in a way that was new and engaging to them.

Students were held to high standards, conceptually and behaviorally, and rose to those standards – in some cases exceeding my expectations, as in the case of technology. I conclude that there is evidence of learning through the course of these three projects. Further, PBL was an effective teaching practice. All five of NCTM's (2000) teaching recommendations were successfully integrated into the PBL goals.

It is worth noting that in the year following this study, the No Child Left Behind legislation went into effect, requiring high-stakes testing for all grades 3-8 and high school. The penalties for unsuccessful mastery of these tests were quite severe, and created a climate of anxiety among administrators. Due to concerns about students not getting enough "direct instruction" a policy was implemented in the study district informally referred to as "if it isn't tested, don't teach it." With that edict, PBL was effectively de-emphasized in favor of teaching toward the test.

Recommendations for Teachers

Based on what I learned from my experience and research I would make the following recommendations to teachers who wish to try similar PBL-based teaching of mathematics with technology and simulations. These recommendations include lessons learned as PBL-based teaching was implemented with students with no prior experience with PBL:

Recommendation 1: If this is the first time students have worked collaboratively, well-defined roles within the groups are essential to avoid issues with group dynamics.

Recommendation 2: If the group dynamic of a "community of learners" is desired, select group-worthy projects. Some aspects of a group-worthy project include having well-defined roles which allow students to internalize a point of view that they can research and debate.

Recommendation 3: A community of learners takes time to form. Three projects were necessary before a true "community" was formed.

Recommendation 4: Less teacher involvement in forming groups may give better results. The groups I formed were less than successful. The groups students naturally formed were more successful. Be mindful to include every student, but honor learning styles and be flexible.

Recommendation 5: Design projects which are rich enough to provide multiple (or no) correct answers. The flaw with Easter Island was that in its pared-down state, one correct answer became the only correct answer. The success of the Dam Project was that it had no correct answer. The success of City of the Future was that it had multiple correct answers.

Recommendation 6: Select projects that are immediately relevant to the students. At eighth grade, no matter how explicitly you make the connections between scenario and real life, an irrelevant scenario will be irrelevant. It is better to select something that is obviously real-life.

Recommendation 7: Practice relevant skills in ways that do not impact creativity. Perhaps, if I had taken time out of the project to practice writing descriptions of graphs that were not related to their final product, they would have been more receptive to the lesson.

Recommendation 8: Be sure "structure" does not inhibit "ownership." Putting too many restrictions and requirements on a project in the name of structure may end up inhibiting creativity and student ownership of the process and products.

Recommendation 9: Whenever possible, incorporate outside review by an authentic audience that is able to provide good constructive feedback.

Recommendation 10: Along with the review process, help students to accept the feedback and use it to make their creations better.

Recommendation 11: When selecting computer-based simulations, be sure to select those which have multiple (or no) correct answers. The Easter Island simulation had an extremely limited set of correct answers, essentially just one. This made it inferior to something like the Dam Project which had no correct answer, or City of the Future which had multiple possible answers.

Recommendations for future research

Based on what I learned from my experience and research I would make the following recommendations to researchers who wish to study similar PBL-based teaching of mathematics with technology and simulations:

Recommendation 12: I made no attempt in this study to evaluate the level of mastery in this study. Future researchers will want to study how much, or how well students learned the math concepts.

Recommendation 13: No attempt was made to evaluate the longevity of the knowledge gained through these projects or their ability to use these concepts and mathematical skills in solving other problems. Further research is needed to evaluate whether, and to what extent, concepts learned in this manner are retained and able to be applied to new situations.

Recommendation 14: With respect to high stakes testing and NCLB, it would benefit all educators to know what impact PBL- and technology-based instructional practices have on student scores.

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Appendix A - NSTA Standards

Table 47. NSTA Standards

Science as Inquiry

1. Abilities necessary to do scientific inquiry
2. Understanding about scientific inquiry

Physical Sciences

Properties and changes of properties in matter
Motions and forces
Transfer of energy

Life Sciences

1. Structure and function in living systems
2. Reproduction and heredity
3. Regulation and behavior
4. Populations and ecosystems
5. Diversity and adaptations of organisms

Earth and Space Sciences

1. Structure of the earth system
2. Earth history
3. Earth in the solar system

Science and Technology

1. Abilities of technology design.
2. Understanding about science and technology

Science from Personal and Social. Perspectives

1. Personal health
2. Populations, resources, and environments
3. Natural hazards
4. Risks and benefits
5. Science and technology in society

History and Nature of Science

1. Science as human endeavor
   Nature of science
   History of science

Appendix B - NCTM STANDARDS 6-8

Table 48. NCTM Standards

Number and Operation Standard		
Benchmark:	**Indicator:** In grades 6–8 all students should—	
Understand numbers, ways of representing numbers, relationships among numbers, and number systems	1	work flexibly with fractions, decimals, and percents to solve problems;
	2	compare and order fractions, decimals, and percents efficiently and find their approximate locations on a number line;
	3	develop meaning for percents greater than 100 and less than 1;
	4	understand and use ratios and proportions to represent quantitative relationships;
	5	develop an understanding of large numbers and recognize and appropriately use exponential, scientific, and calculator notation;
	6	use factors, multiples, prime factorization, and relatively prime numbers to solve problems;
	7	develop meaning for integers and represent and compare quantities with them.
Understand meanings of operations and how they relate to one another	1	understand the meaning and effects of arithmetic operations with fractions, decimals, and integers;
	2	use the associative and commutative properties of addition and multiplication and the distributive property of multiplication over addition to simplify computations with integers, fractions, and decimals;
	3	understand and use the inverse relationships of addition and subtraction, multiplication and division, and squaring and finding square roots to simplify computations and solve problems.
Compute fluently and make reasonable estimates	1	select appropriate methods and tools for computing with fractions and decimals from among mental computation, estimation, calculators or computers, and paper and pencil, depending on the situation, and apply the selected methods;
	2	develop and analyze algorithms for computing with fractions, decimals, and integers and develop fluency in their use;

Benchmark	No.	Indicator
	3	develop and use strategies to estimate the results of rational-number computations and judge the reasonableness of the results;
	4	develop, analyze, and explain methods for solving problems involving proportions, such as scaling and finding equivalent ratios.

ALGEBRA Standard		
Benchmark:	**Indicator:** **In grades 6–8 all students should—**	
Understand patterns, relations, and functions	1	represent, analyze, and generalize a variety of patterns with tables, graphs, words, and, when possible, symbolic rules;
	2	relate and compare different forms of representation for a relationship;
	3	identify functions as linear or nonlinear and contrast their properties from tables, graphs, or equations.
Represent and analyze mathematical situations and structures using algebraic symbols	1	develop an initial conceptual understanding of different uses of variables;
	2	explore relationships between symbolic expressions and graphs of lines, paying particular attention to the meaning of intercept and slope;
	3	use symbolic algebra to represent situations and to solve problems, especially those that involve linear relationships;
	4	recognize and generate equivalent forms for simple algebraic expressions and solve linear equations
Use mathematical models to represent and understand quantitative relationships	1	model and solve contextualized problems using various representations, such as graphs, tables, and equations.
Analyze change in various contexts	1	use graphs to analyze the nature of changes in quantities in linear relationships.

GEOMETRY Standard		
Benchmark:	**Indicator:** **In grades 6–8 all students should—**	
Analyze characteristics and properties of two- and three-dimensional geometric shapes and develop mathematical arguments about geometric relationships	1	precisely describe, classify, and understand relationships among types of two- and three-dimensional objects using their defining properties;
	2	understand relationships among the angles, side lengths, perimeters, areas, and volumes of similar objects;
	3	create and critique inductive and deductive arguments concerning geometric ideas and relationships, such as congruence, similarity, and the Pythagorean relationship.

Specify locations and describe spatial relationships using coordinate geometry and other representational systems	1	use coordinate geometry to represent and examine the properties of geometric shapes;
	2	use coordinate geometry to examine special geometric shapes, such as regular polygons or those with pairs of parallel or perpendicular sides.
Apply transformations and use symmetry to analyze mathematical situations	1	describe sizes, positions, and orientations of shapes under informal transformations such as flips, turns, slides, and scaling;
	2	examine the congruence, similarity, and line or rotational symmetry of objects using transformations.
Use visualization, spatial reasoning, and geometric modeling to solve problems	1	draw geometric objects with specified properties, such as side lengths or angle measures;
	2	use two-dimensional representations of three-dimensional objects to visualize and solve problems such as those involving surface area and volume;
	3	use visual tools such as networks to represent and solve problems;
	4	use geometric models to represent and explain numerical and algebraic relationships;
	5	recognize and apply geometric ideas and relationships in areas outside the mathematics classroom, such as art, science, and everyday life.

MEASUREMENT Standard		
Benchmark:	**Indicator:**	**In grades 6–8 all students should—**
Understand measurable attributes of objects and the units, systems, and processes of measurement	1	understand both metric and customary systems of measurement;
	2	understand relationships among units and convert from one unit to another within the same system;
	3	understand, select, and use units of appropriate size and type to measure angles, perimeter, area, surface area, and volume.
Apply appropriate techniques, tools, and formulas to determine measurements	1	use common benchmarks to select appropriate methods for estimating measurements;
	2	select and apply techniques and tools to accurately find length, area, volume, and angle measures to appropriate levels of precision;
	3	develop and use formulas to determine the circumference of circles and the area of triangles, parallelograms, trapezoids, and circles and develop strategies to find the area of more-complex shapes;

	4	develop strategies to determine the surface area and volume of selected prisms, pyramids, and cylinders;
	5	solve problems involving scale factors, using ratio and proportion;
	6	solve simple problems involving rates and derived measurements for such attributes as velocity and density.

DATA ANALYSIS AND PROBABILITY Standard		
Benchmark: **Instructional programs from prekindergarten through grade 12 should enable all students to—**		**Indicator:** **In grades 6–8 all students should—**
Formulate questions that can be addressed with data and collect, organize, and display relevant data to answer them	1	formulate questions, design studies, and collect data about a characteristic shared by two populations or different characteristics within one population;
	2	select, create, and use appropriate graphical representations of data, including histograms, box plots, and scatterplots.
Select and use appropriate statistical methods to analyze data	1	find, use, and interpret measures of center and spread, including mean and interquartile range;
	2	discuss and understand the correspondence between data sets and their graphical representations, especially histograms, stem-and-leaf plots, box plots, and scatterplots.
Develop and evaluate inferences and predictions that are based on data	1	use observations about differences between two or more samples to make conjectures about the populations from which the samples were taken;
	2	make conjectures about possible relationships between two characteristics of a sample on the basis of scatterplots of the data and approximate lines of fit;
	3	use conjectures to formulate new questions and plan new studies to answer them.
Understand and apply basic concepts of probability	1	understand and use appropriate terminology to describe complementary and mutually exclusive events;
	2	use proportionality and a basic understanding of probability to make and test conjectures about the results of experiments and simulations;
	3	compute probabilities for simple compound events, using such methods as organized lists, tree diagrams, and area models.

PROBLEM SOLVING STANDARD

Indicator: In grades 6–8 all students should—

1. build new mathematical knowledge through problem solving;

2. solve problems that arise in mathematics and in other contexts;

3. apply and adapt a variety of appropriate strategies to solve problems;

4. monitor and reflect on the process of mathematical problem solving.

REASONING AND PROOF Standard

Indicator: In grades 6–8 all students should—

1.recognize reasoning and proof as fundamental aspects of mathematics;

2.make and investigate mathematical conjectures;

3. develop and evaluate mathematical arguments and proofs;

4. select and use various types of reasoning and methods of proof

COMMUNICATIONS Standard

Indicator: In grades 6–8 all students should—

1. organize and consolidate their mathematical thinking through communication;

2. communicate their math thinking coherently and clearly to peers, teachers, and others;

3. analyze and evaluate the mathematical thinking and strategies of others;

4. use the language of mathematics to express mathematical ideas precisely.

CONNECTIONS Standard

Indicator: In grades 6–8 all students should—

1. recognize and use connections among mathematical ideas;

2. understand how mathematical ideas interconnect and build on one another to produce a coherent whole;

3. recognize and apply mathematics in contexts outside of mathematics.

REPRESENTATION Standard

Indicator: In grades 6–8 all students should—

1. create and use representations to organize, record, and communicate mathematical ideas;

2. select, apply, and translate among mathematical representations to solve problems;

3. use representations to model and interpret physical, social, and math phenomena.

Appendix C - NCSS Standards

National Council of Social Studies Standards

I. culture:

a. compare similarities and differences in the ways groups, societies, and cultures meet human needs and concerns;
b. explain how information and experiences may be interpreted by people from diverse cultural perspectives and frames of reference;
c. explain and give examples of how language, literature, the arts, architecture, other artifacts, traditions, beliefs, values, and behaviors contribute to the development and transmission of culture;
d. explain why individuals and groups respond differently to their physical and social environments and/or changes to them on the basis of shared assumptions, values, and beliefs;
e. articulate the implications of cultural diversity, as well as cohesion, within and across groups.

II. Time, Continuity, Change

a. demonstrate an understanding that different scholars may describe the same event or situation in different ways but must provide reasons or evidence for their views;
b. identify and use key concepts such as chronology, causality, change, conflict, and complexity to explain, analyze, and show connections among patterns of historical change and continuity;
c. identify and describe selected historical periods and patterns of change within and across cultures, such as the rise of civilizations, the development of transportation systems, the growth and breakdown of colonial systems, and others;
d. identify and use processes important to reconstructing and reinterpreting the past, such as using a variety of sources, providing, validating, and weighing evidence for claims, checking credibility of sources, and searching for causality;
e. develop critical sensitivities such as empathy and skepticism regarding attitudes, values, and behaviors of people in different historical contexts;
f. use knowledge of facts and concepts drawn from history, along with methods of historical inquiry, to inform decision making about and action-taking on public issues.

III. People, places, environment

a. elaborate mental maps of locales, regions, and the world that demonstrate understanding of relative location, direction, size, and shape;
b. create, interpret, use, and distinguish various representations of the earth, such as maps, globes, and photographs;
c. use appropriate resources, data, sources, and geographic tools such as aerial photographs, satellite images, geographic information systems (GIS), map projections, and cartography to generate, manipulate, and interpret information such as atlases, data bases, grid systems, charts, graphs, and maps;

d. estimate distance, calculate scale, and distinguish other geographic relationships such as population density and spatial distribution patterns;
e. locate and describe varying landforms and geographic features, such as mountains, plateaus, islands, rain forests, deserts, and oceans, and explain their relationships within the ecosystem;
f. describe physical system changes such as seasons, climate and weather, and the water cycle and identify geographic patterns associated with them;
g. describe how people create places that reflect cultural values and ideals as they build neighborhoods, parks, shopping centers, and the like;
h. examine, interpret, and analyze physical and cultural patterns and their interactions, such as land use, settlement patterns, cultural transmission of customs and ideas, and ecosystem changes;
i. describe ways that historical events have been influenced by, and have influenced, physical and human geographic factors in local, regional, national, and global settings;
j. observe and speculate about social and economic effects of environmental changes and crises resulting from phenomena such as floods, storms, and drought;
k. propose, compare, and evaluate alternative uses of land and resources in communities, regions, nations, and the world.

IV Individual identity development

a. relate personal changes to social, cultural, and historical contexts; describe personal connections to place — as associated with community, nation, and world;
b. describe the ways family, gender, ethnicity, nationality, and institutional affiliations contribute to personal identity;
c. relate such factors as physical endowment and capabilities, learning, motivation, personality, perception, and behavior to individual development;
d. identify and describe ways regional, ethnic, and national cultures influence individuals' daily lives;
e. identify and describe the influence of perception, attitudes, values, and beliefs on personal identity;
f. identify and interpret examples of stereotyping, conformity, and altruism;
g. work independently and cooperatively to accomplish goals.

V. Individuals, groups, institutions

a. demonstrate an understanding of concepts such as role, status, and social class in describing the interactions of individuals and social groups
b. analyze group and institutional influences on people, events, and elements of culture;
c. describe the various forms institutions take and the interactions of people with institutions;
d. identify and analyze examples of tensions between expressions of individuality and group or institutional efforts to promote social conformity;
e. identify and describe examples of tensions between belief systems and government policies and laws;
f. describe the role of institutions in furthering both continuity and change;
g. apply knowledge of how groups and institutions work to meet individual needs and promote the common good.

VI. Power, authority, govt.

a. examine persistent issues involving the rights, roles, and status of the individual in relation to the general welfare;

b. describe the purpose of government and how its powers are acquired, used, and justified;
c. analyze and explain ideas and governmental mechanisms to meet needs and wants of citizens, regulate territory, manage conflict, and establish order and security;
d. describe the ways nations and organizations respond to forces of unity and diversity affecting order and security;
e. identify and describe the basic features of the political system in the United States, and identify representative leaders from various levels and branches of government;
f. explain conditions, actions, and motivations that contribute to conflict and cooperation within and among nations;
g. describe and analyze the role of technology in communications, transportation, information-processing, weapons development, or other areas as it contributes to or helps resolve conflicts;
h. explain and apply concepts such as power, role, status, justice, and influence to the examination of persistent issues and social problems;
i. give examples and explain how governments attempt to achieve their stated ideals at home and abroad.

VII. production, distr., consumption

a. give and explain examples of ways that economic systems structure choices about how goods and services are to be produced and distributed;
b. describe the role that supply and demand, prices, incentives, and profits play in determining what is produced and distributed in a competitive market system;
c. explain the difference between private and public goods and services;
d. describe a range of examples of the various institutions that make up economic systems such as households, business firms, banks, government agencies, labor unions, and corporations;
e. describe the role of specialization and exchange in the economic process;
f. explain and illustrate how values and beliefs influence different economic decisions;
g. differentiate among various forms of exchange and money;
h. compare basic economic systems according to who determines what is produced, distributed, and consumed;
i. use economic concepts to help explain historical and current developments and issues in local, national, or global contexts;
j. use economic reasoning to compare different proposals for dealing with a contemporary social issue such as unemployment, acid rain, or high quality education.

VIII. Sci, Tech, Society

a. examine and describe the influence of culture on scientific and technological choices and advancement, such as in transportation, medicine, and warfare;
b. show through specific examples how science and technology have changed people's perceptions of the social and natural world, such as in their relationship to the land, animal life, family life, and economic needs, wants, and security;
c. describe examples in which values, beliefs, and attitudes have been influenced by new scientific and technological knowledge, such as the invention of the printing press, conceptions of the universe, applications of atomic energy, and genetic discoveries;
d. explain the need for laws and policies to govern scientific and technological applications, such as in the safety and well-being of workers and consumers and the regulation of utilities, radio, and television;
e. seek reasonable and ethical solutions to problems that arise when scientific advancements and social norms or values come into conflict.

IX. Global

a. describe instances in which language, art, music, belief systems, and other cultural elements can facilitate global understanding or cause misunderstanding;
b. analyze examples of conflict, cooperation, and interdependence among groups, societies, and nations;
c. describe and analyze the effects of changing technologies on the global community;
d. explore the causes, consequences, and possible solutions to persistent, contemporary, and emerging global issues, such as health, security, resource allocation, economic development, and environmental quality;
e. describe and explain the relationships and tensions between national sovereignty and global interests, in such matters as territory, natural resources, trade, use of technology, and welfare of people;
f. demonstrate understanding of concerns, standards, issues, and conflicts related to universal human rights;
g. identify and describe the roles of international and multinational organizations.

X. Civics

examine the origins and continuing influence of key ideals of the democratic republican form of government, such as individual human dignity, liberty, justice, equality, and the rule of law;

identify and interpret sources and examples of the rights and responsibilities of citizens;

locate, access, analyze, organize, and apply information about selected public issues — recognizing and explaining multiple points of view;

practice forms of civic discussion and participation consistent with the ideals of citizens in a democratic republic;

explain and analyze various forms of citizen action that influence public policy decisions;

identify and explain the roles of formal and informal political actors in influencing and shaping public policy and decision making;

analyze the influence of diverse forms of public opinion on the development of public policy and decision making;

analyze the effectiveness of selected public policies and citizen behaviors in realizing the stated ideals of a democratic republican form of government;

explain the relationship between policy statements and action plans used to address issues of public concern;

examine strategies designed to strengthen the "common good," which consider a range of options for citizen action.

Appendix D - NCTE Standards

National Council of Teachers of English Standards

1. Students read a wide range of print and non-print texts to build an understanding of texts, of themselves, and of the cultures of the United States and the world; to acquire new information; to respond to the needs and demands of society and the workplace; and for personal fulfillment. Among these texts are fiction and nonfiction, classic and contemporary works.

2. Students read a wide range of literature from many periods in many genres to build an understanding of the many dimensions (e.g., philosophical, ethical, aesthetic) of human experience.

3. Students apply a wide range of strategies to comprehend, interpret, evaluate, and appreciate texts. They draw on their prior experience, their interactions with other readers and writers, their knowledge of word meaning and of other texts, their word identification strategies, and their understanding of textual features (e.g., sound-letter correspondence, sentence structure, context, graphics).

4. Students adjust their use of spoken, written, and visual language (e.g., conventions, style, vocabulary) to communicate effectively with a variety of audiences and for different purposes.

5. Students employ a wide range of strategies as they write and use different writing process elements appropriately to communicate with different audiences for a variety of purposes.

6. Students apply knowledge of language structure, language conventions (e.g., spelling and punctuation), media techniques, figurative language, and genre to create, critique, and discuss print and non-print texts.

7. Students conduct research on issues and interests by generating ideas and questions, and by posing problems. They gather, evaluate, and synthesize data from a variety of sources (e.g., print and non-print texts, artifacts, people) to communicate their discoveries in ways that suit their purpose and audience.

8. Students use a variety of technological and information resources (e.g., libraries, databases, computer networks, video) to gather and synthesize information and to create and communicate knowledge.

9. Students develop an understanding of and respect for diversity in language use, patterns, and dialects across cultures, ethnic groups, geographic regions, and social roles.

10. Students whose first language is not English make use of their first language to develop competency in the English language arts and to develop understanding of content across the curriculum.

11. Students participate as knowledgeable, reflective, creative, and critical members of a variety of literacy communities.

12. Students use spoken, written, and visual language to accomplish their own purposes (e.g., for learning, enjoyment, persuasion, and the exchange of information).

Appendix E - NETS/ISTE Standards

Technology Foundation Standards for All Students

1) Basic operations and concepts
   a) Students demonstrate a sound understanding of the nature and operation of technology systems.
   b) Students are proficient in the use of technology.

2) Social, ethical, and human issues
   a) Students understand the ethical, cultural, and societal issues related to technology.
   b) Students practice responsible use of technology systems, information, and software.
   c) Students develop positive attitudes toward technology uses that support lifelong learning, collaboration, personal pursuits, and productivity.

3) Technology productivity tools
   a) Students use technology tools to enhance learning, increase productivity, and promote creativity.
   b) Students use productivity tools to collaborate in constructing technology-enhanced models, prepare publications, and produce other creative works.

4) Technology communications tools
   a) Students use telecommunications to collaborate, publish, and interact with peers, experts, and other audiences.
   b) Students use a variety of media and formats to communicate information and ideas effectively to multiple audiences.

5) Technology research tools
   a) Students use technology to locate, evaluate, and collect information from a variety of sources.
   b) Students use technology tools to process data and report results.
   c) Students evaluate and select new information resources and technological innovations based on the appropriateness for specific tasks.

6) Technology problem-solving and decision-making tools
   a) Students use technology resources for solving problems and making informed decisions.
   b) Students employ technology in the development of strategies for solving problems in the real world.

Appendix F - Other Curricular Standards Correlation

National Council of Social Studies Correlations

Stacks 1d, 2d, 4a and 5a did not show evidence of meeting NCSS standards 1a, which ask students to relate the ways civilizations and cultures deal with need. Additionally, those stacks also did not show evidence of meeting Standard 7b, which asks students to understand concepts of supply and demand. Stacks 1d and 5a also did not meet standard 1b, which requires students to explain how information would be interpreted by persons with different cultural perspectives (see Table F.1).

Table 49 - Stacks showing evidence of meeting NCSS standards

	NCSS Standards											
Stack	1a	1b	2a	2b	3a	3b	3c	4a	7a	7b	7c	10a
1a	X	X	X	X	X	X	X	X	X	X	X	X
1d			X	X	X	X	X	X	X		X	X
2a	X	X	X	X	X	X	X	X	X	X	X	X
2d		X	X	X	X	X	X	X	X		X	X
3a	X	X	X	X	X	X	X	X	X	X	X	X
4a		X		X	X	X	X	X	X		X	X
5a			X	X	X	X	X	X	X		X	X
6a	X	X	X	X	X	X	X	X	X	X	X	X
7a	X	X	X	X	X	X			X	X		

8a	X	X	X	X	X	X	X		X		X	

National Council of Teachers of English Standards Correlations

All stacks met all relevant standards for project one. This may be related to the fact that the Language Arts teacher (T-2) was present and interacting with students during this project (See Table F.2).

Table 50 - Stacks showing evidence of meeting NCTE standards for Project 1

	NCTE Standards						
STACK	**1**	**3**	**4**	**6**	**7**	**11**	**12**
1a	X	X	X	X	X	X	X
1d	X	X	X	X	X	X	X
2a	X	X	X	X	X	X	X
2d	X	X	X	X	X	X	X
3a	X	X	X	X	X	X	X
4a	X	X	X	X	X	X	X
5a	X	X	X	X	X	X	X
6a	X	X	X	X	X	X	X
7a	X	X	X	X	X	X	X
8a	X	X	X	X	X	X	X

National Science Teachers Association Standards Correlations

Stack 7a did not meet any of the life science standards required for this project. Stack 1d did not meet Life Science standards 3 and 5, which are “Regulation and Behavior” and “Diversity and Adaptation” respectively. Stacks 4a and 6a did not meet Science in Personal and

Social Perspectives standards 3 and 4, which are “Natural Hazards” and “Risks and Benefits” respectively (See Table F.3).

Table 51 - Stacks showing evidence of meeting NSTA standards for Project 1.

	Life Sciences				**Science in Personal and Social Perspectives**		
Stack	2	3	4	5	2	3	4
1a	X	X	X	X	X	X	X
1d	X		X		X	X	X
2a	X	X	X	X	X	X	X
2d	X	X	X	X	X	X	X
3a	X	X	X	X	X	X	X
4a	X	X	X	X	X		
5a	X	X	X	X	X	X	X
6a	X	X	X	X	X		
7a					X	X	X
8a	X	X	X	X	X	X	X

National Science Teachers Association Standards

Stack A showed evidence of meeting all three Life Sciences standards, while Stack B did not meet Life Science standard 5, which relates diversity and adaptation of organisms. Stack B showed evidence of both Science and Technology standards, while Stack A did not show evidence of Science and Technology standard 1. Both stacks met all Science in Personal and Social Perspectives standards (See Table F.4)

Table 52 - NSTA standards evident within Project 2 stacks.

NSTA Standards									
	Life Sciences			**Science and Technology**		**Science in Personal and Social Perspectives**			
	3	4	5	1	2	2	3	4	5
Stack A	X	X	X		X	X	X	X	X
Stack B	X	X		X	X	X	X	X	X

National Council of Social Studies Standards

Stack A did not show evidence of meeting standards 7d and 9e, which represent the organization of institutions within a culture, and the tensions between national sovereignty and natural resource utilization and the welfare of citizens. Stack B did not show evidence of standard 3i, which relates how events in history affect cultures (see Table F.5)

Table 53 – NCSS standards evident within Project 2 stacks.

	1b	1d	3h	3i	3j	3k	5f	5g	7b	7d	9d	9e	10d
Stack A	X	X	X	X	X	X	X	X	X		X		X
Stack B	X	X	X		X	X	X	X	X	X	X	X	X

National Council of Teachers of English Standards

Both stacks met all required NCTE standards for project 2 (see table F.6).

Table 54 – NCTE standards evident within Project 2 stacks.

	NCTE Standards								
Stack	**1**	**3**	**4**	**5**	**6**	**7**	**8**	**11**	**12**
Stack A	X	X	X	X	X	X	X	X	X
Stack B	X	X	X	X	X	X	X	X	X

National Council of Teachers of English Standards

Stack G8 had difficulty meeting NCTE standards 4 and 5, both of which involve writing to intended audiences. (See Table F.7)

Table 55 - Evidence of meeting NCTE standards, Project 3

	NCTE Standards					
Stack	**4**	**5**	**7**	**8**	**11**	**12**
B4	X	X	X	X	X	X
B7	X	X	X	X	X	X
G10	X	X	X	X	X	X
G11	X	X	X	X	X	X
G13	X	X	X	X	X	X
G15	X	X	X	X	X	X
G3	X	X	X	X	X	X
G5	X	X	X	X	X	X
G6	X	X	X	X	X	X
G7	X	X	X	X	X	X
G8			X	X	X	X
G9	X	X	X	X	X	X

National Council of Social Studies Standards

Standard 6g, which is the use of technology to solve problems, seemed difficult for everyone to meet except G10 and G15. Additionally, standard 3g was not met by B7, G11, G5, G7, G8, or G9. Stacks B7 and G11 also did not meet Standard 3c (See Table F.8)

Table 56 - Evidence of stacks meeting NCSS standards

	NCSS standards									
Stack	**1d**	**3b**	**3c**	**3g**	**3k**	**6a**	**6c**	**6g**	**8d**	**9b**
B4	X	X	X	X	X	X	X		X	X
B7	X	X			X	X	X		X	X
G10	X	X	X	X	X	X	X	X	X	X
G11	X	X			X	X	X		X	X
G13	X	X	X	X	X	X	X		X	X
G15	X	X	X	X	X	X	X	X	X	X
G3	X	X	X	X	X	X	X		X	X
G5	X	X	X		X	X	X		X	X
G6	X	X	X	X	X	X	X		X	X
G7	X	X	X		X	X	X		X	X
G8	X	X	X		X	X	X		X	X
G9	X	X	X		X	X	X		X	X

National Science Teachers Association Standards

Meeting the required Science standards appeared difficult to meet, as G5 was the only stack to do so. Stack G15 met three of four standards, and B7, G10, G13, G3 and G7 met only two of four standards (See Table F.9).

Table 579 - NSTA standards correlations

	Science and Technology	Science in Personal and Social Perspectives		
Stack	**2**	**2**	**3**	**4**
B4				
B7	X			X
G10		X		X
G11				
G13		X		X
G15	X	X		X
G3		X		X
G5	X	X	X	X
G6				
G7			X	X
G8				X
G9				

Appendix G - Other Research on This Same Classroom

During the 2001-02 school year, Mark Viner and I conducted our respective dissertation research in my mathematics classroom. This was done with the full knowledge and approval of our respective dissertation committees.

Since our dissertations study different aspects of the same population, during the same time period and during the same treatment, several aspects of the data will understandably be similar. Student quotations during videotaped interviews, teacher observations, and the students' artifacts will notably be identical. The themes, questions, and analyses of these items are distinctly different, and seek to illuminate different research questions.

The reader may wish to consult Mark Viner's dissertation for additional information about this project-based classroom:

Viner, Mark (2003) Observations and exploration of a sequence of design environments: Students designing a series of multimedia projects. Ph.D. dissertation, Kansas State University, United States -- Kansas.