THE IMPACT OF TECHNOLOGY ON TEACHING AND LEARNING IN AN ELEMENTARY SCIENCE CLASSROOM

by

KATHARINE POPEJOY

B.A., The University of Colorado, 1990
M. Ed., Western Washington University, 1997

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

in

THE FACULTY OF GRADUATE STUDIES

(Curriculum Studies)

THE UNIVERSITY OF BRITISH COLUMBIA

December 5, 2006

Abstract

This dissertation documents a case study of a 4^{th}-5^{th} grade science classroom, equipped with eight desktop computers, in which the classroom teacher and her students used technology tools to enhance instruction and learning; specifically in the areas of astronomy and space exploration. My research questions were:

1. How can the imaginative integration of technology tools extend the practices of a teacher and her students in an elementary science classroom? How do these teacher and student practices interact?
2. What conditions/structures were present in this case to nurture the development of technology as an imaginative extension of the complex learning environment? How may these conditions be considered as 'enabling constraints'?

I employed case study methodology and used complexity theory as an interpretive lens for better understanding the dynamic features of technology use in the classroom. The research environment exhibited many of the characteristics of a complex entity; thriving in the fertile space at the edge of chaos. To capture the complex nature of the interactions in a collective classroom setting, I became a member of the community, and employed the methods of participant research.

Easily accessible computers enabled a series of student science projects of an expanded and open nature; within the context of an adaptive learning environment. The teacher and her students made significant modifications to their existing teaching and learning practices – with changes occurring in the teacher's instructional role and assigned tasks, and the students becoming much more engaged with the subject matter through extensive research projects.

In this open learning system, complex adaptation and change were continually occurring in all members; teacher, students, curriculum materials, and technology tools. The computers, with their continuing flow of information and experience, provided for a great deal of the open nature of the emergent classroom community. In summary, the way in which this classroom was structured allowed for new and unique ideas, practices, and learning to emerge, thus providing a rich, diverse and adaptive experience for all participants.

Table of Contents

List of Tables

List of Figures

Acknowledgements

I would like to gratefully and sincerely thank my Research Supervisor, Dr. Gaalen Erickson for his guidance, understanding, and patience during my graduate studies at UBC. His mentorship was invaluable as I worked through this complex research project. I would also like to thank the members of my Supervisory Committee, Dr. Samia Khan and Dr. Jolie Mayer-Smith. Without their patient faith in my work, I would have not have been able to complete this dissertation.

I would also like to recognize Belinda Knudson and the members of her 4th/5th grade class at Bayview Elementary School for the academic year 2002-03. Their wholehearted acceptance of my presence afforded me a true window into their complex learning community, and for that I am truly grateful.

Chapter One: Introduction to the Study

As technology tools become increasingly common in schools, educators are confronted with a wide range of views of what technology is and what purposes it should serve in instructional settings. Many traditional research studies have taken the 'horserace approach,' i.e., "does x produce better learning results than y" (Salomon, 2000)? Further, these studies usually have compared specific technological innovations as they affect student learning, resulting in a list of effective (and ineffective) software, hypermedia, etc. However, the rate of technological advance means that many of these applications are soon obsolete (Zhao, Pugh, Sheldon, & Byers, 2002). These types of studies do not take into account the complex aspects of the classroom, such as teacher and student attitudes, tasks, curricular content and specific pedagogical contexts. As Zhao et al. (2002) continue, "there is a conspicuous lack of attention to the complexities and intricacies of how classroom teachers actually incorporate technology in their teaching" (p. 483). In this research study, I explored the practices of an elementary teacher and her students as they worked to use technology tools to enhance instruction and learning; specifically in the area of science.

To gain an understanding of these practices, in 2002 I established myself as a participant researcher in a 4th/5th grade classroom at Bayview Elementary School.[1] During my five months in the classroom, I was able to live the life of a researcher, teacher and learner as I worked alongside Belinda Knudson and 24 students, studying astronomy and space exploration. This classroom was equipped with eight Gateway desktop computers with high-speed Internet connections, making it a classroom with a favorable ratio of computers to

[1] All names in this dissertation are pseudonyms.

children as compared to the then national average of 5.6 students per computer (Technology Counts, 2003).

General Problem Area

Over the last three decades, reformers have portrayed technology as a tool to transform schools (Cuban, 2001). The push to incorporate technology in classroom teaching grew even stronger as the Internet became more easily accessible in 1995 with the development of user-friendly World Wide Web interfaces such as Mosaic. In the United States, by 2002, 99% of public schools were wired for the Internet, with 87% of classrooms wired. In addition, in 73% of U.S schools, at least half of the teachers reported using the Internet for instruction (Technology Counts, 2003). With almost universal access to computers and the Internet in schools, the challenge then became that of developing the capacity to use technology effectively. In 2001, the 'No Child Left Behind' Act mandated that states allocate 25% of *federal* technology dollars to staff development. However, in 2002 states spent an average of only 15% of *total* technology dollars in staff development (Technology Counts, 2003).

Studies have shown that most teachers see the importance of using technology in their classrooms, but they often lack a clear idea of how technology can be used to support sound educational pedagogy (Beichner, 1993; Ertmer, Gopalakrishnan, & Ross, 2001). Not only do the tools change at a rapid pace, but so do views about how the tools should be used in the classroom.

Specific Research Focus

For this research study, I decided to explore some of the ways a teacher and students would utilize the tools in a technology-rich classroom to learn science. My research questions were structured to allow items of interest to emerge within a complex framework. This was not to be an evaluative study in which I endeavored to answer questions about which applications worked best, or what methods of teaching were better for learning. To reflect this emergent perspective, my research questions were the following:

1. How can the imaginative integration of technology tools extend the practices of a teacher and students in an elementary science classroom? How do these teacher and student practices interact?
2. What conditions/structures were present in this case to nurture the development of technology as an imaginative extension of the complex learning environment? How may these conditions be considered as 'enabling constraints'?

As a participant researcher, I was involved directly in the unfolding events of the classroom. Though my primary interest in the classroom was research, Belinda and I set some goals in our planning process. First, we wanted this project to benefit the students. This meant that we wanted the students to learn more about astronomy through the use of technology tools, hopefully in ways that would be rich and rewarding. Second, we wanted Belinda to learn about ways she could use technology in her instruction across all content areas, but most specifically in science. Third, we wanted to do things that Belinda could then replicate in later years when I was no longer in the classroom. We did not wish to develop tools or methods that were not reasonable for one teacher to do on her own. These last two goals related to professional development for Belinda. As I will relate in later chapters, Belinda had received her classroom computers through a grant, but professional development was not provided. We believed that our working together might bridge some of the professional development gaps for Belinda. This type of job-embedded, contextual professional development is what Belinda desired, and also what much of the literature recommends (DuFour, Eaker, & DuFour, 2005).

As I mentioned above, I existed in the space of a participant researcher while developing this case study. Through the case presented in this dissertation, I hope to illuminate some of the processes and practices of an elementary classroom community as technology is integrated into their science curriculum. I will describe some of the powerful uses of technology, but also provide examples of frustrating inadequacies.

Significance of the Study

The conclusions that I draw from Bayview classroom events, practices, and context are not intended to be universally valid generalizations. In this respect the specific assertions presented here may be limited to the research environment. However, through this qualitative case study, I hope to stimulate further thought and reflection upon the part of the reader. In the language of Stake (1995), my goal is to stimulate 'naturalistic generalization' in which conclusions are arrived at through the vicarious experience of the Bayview classroom. The reader, being familiar with other cases and experiences, is invited to engage with this case in order to construct broader meaning.

In this research, I used complexity theory as a lens through which to interpret the events and practices which emerged in the classroom. Complexity theory or science, "deals with self-organizing, self-maintaining, adaptive phenomena – in brief, with systems that learn" (Davis & Simmt, 2006, p. 295). The Bayview classroom was a dynamic system, exhibiting many of the characteristics of a complex entity; thriving in the fertile space at the edge of chaos. In addition, the use of case study methodology in this research provides a form of analytical generalizability (Yin, 1994) for the use of complexity theory as an interpretive lens for better understanding the dynamical features of technology use in a classroom.

Delimitations and Limitations of this Study

My research project was confined to a single classroom, its teacher Belinda, and 24 students, with consideration given only to the larger school, district, and state structures as they impacted upon the classroom community. There was a student teacher in the classroom for part of the research period, but I did not include her in this study. Nor did I examine the relations of parents to students and the classroom community, though many parents were present as helpers. I did not examine in detail the use of computers at home, other than to administer a short, written survey to students at the beginning of the project. Lastly, though most subjects were integrated in Belinda's classroom, I focused for the most part on work in science, specifically in astronomy and space exploration.

This case study was limited as it is not completely replicable, as is often the case with many forms of participant and/or qualitative research. There was no control classroom without computers in place in order to make comparisons. The knowledge claims I make are based upon a wide array of data, some of which is self-reported via interviews with Belinda and her students. Notably, when I discuss differences between this class at this time and Belinda's previous classes, I rely on her insights. In this dissertation, I provide a rich description of how one elementary science classroom community interacted with computers; a five month 'snapshot' of a particular class, at a particular time, and in a particular place. My presence in the Bayview classroom as a participant researcher was time consuming, and could not be easily duplicated with limited resources. Even though we found that Belinda and her students benefited from my presence in the Bayview classroom, this is not a professional development model that could be easily delivered, due to cost and time constraints. However, my description provides insight for those interested in how technology can extend teacher and student abilities and practices in elementary science classrooms. Lastly, some of the conclusions that I draw from this research can be extended to other classroom communities by teachers and researchers as they reflect upon the commonalities and differences in their respective settings.

Overview of the Dissertation

This first chapter introduces the topics of my research, and provides an overview of the dissertation. The research questions are presented and placed in professional and societal contexts. The research methodology is introduced, along with a brief rationale for the study.

Chapter Two provides a review of the educational technology literature. In this chapter, I explore broad categories of practice for educational technology in the classroom; various current applications of technology in elementary classrooms; the issues and problems associated with the introduction and use of educational technology in the school setting; and teacher professional development in technology.

As I have chosen to frame my research within the field of complexity theory, Chapter Three provides an overview of this theoretical perspective. The origins of complexity theory as a contrasting paradigm to reductionism in the natural sciences are explored, and related terms are defined. Then, I discuss the advent of complexity as a framework for social sciences research; moving into its applications in education. More specifically, I discuss the role of complexity theory in learning and cognition; and then move on to how a classroom can be examined through a complexity lens.

In Chapter Four, I develop the concepts of participant research as a methodology, and place it in the context of qualitative research, case study and ethnography. In order to shed light upon the complex environment of the classroom, I decided to become a member of the community, and employ the methodology of an in-depth, participatory, case study. In this chapter I explore my role in the Bayview classroom, delineate the limitations and methods of data collection, and describe the data analysis process.

In Chapter Five, I explore the characteristics that enabled and nurtured the complex learning system of the Bayview classroom. I examine the practice of the classroom teacher, Belinda, as she set up and maintained an environment conducive to taking risks, an important theme of the classroom. Belinda relished the opportunity to set her students free to learn about astronomy and space exploration using the computers. The onus for learning was placed upon the students, and the classroom community as a whole, through the ways that Belinda consciously distributed power and control from her to the students. Belinda controlled the basic structures of the classroom, but avoided 'micro-managing' the details of the learning environment.

In Chapter Six, I specifically examine the practices of the students and Belinda as they worked with the technology tools in the classroom. Using the Internet-connected computers, the students were able to research a wide range of topics in the area of astronomy. Here I describe specific research projects that were developed by the students for an authentic audience, and also explain how technology tools enabled a higher level of learning for the students.

Chapter Seven is devoted to a discussion and analysis of the case data presented in Chapters Five and Six, employing the constructs emerging from complexity theory. The complex nature of the Bayview classroom can be construed in terms of the conditions or structures which nurtured both student and teacher learning resulting from the use of technology as an imaginative extension of the learning environment.

In the final chapter, Chapter Eight, I present an overall summary and discussion of the study and respond to my original research questions. I summarize the main educational technology outcomes, and the complex relationships within the classroom community. I briefly reiterate how the technology tools extended the practices and abilities of the teacher and students in the Bayview classroom. The role of the case study researcher is often one of interpreter, and in the discussion section of this chapter, I explore how my study fits into the context of the educational technology literature. Lastly, I suggest possible avenues for future research.

Chapter Two: Technology in the Classroom

In this chapter, I will provide a context for the use of educational technology in the classroom, with an emphasis on the elementary science classroom. For the purposes of this chapter (and dissertation), educational technology includes: a) computers and other associated hardware, such as projectors, probes, and handhelds, b) various software programs, and c) tools available via the World Wide Web. Following this brief introductory section, I explore broad categories of practice for educational technology in the classroom; various current applications of educational technology in elementary classrooms; the issues and problems associated with educational technology in the school setting; and concerns relating to professional development and technology. Lastly, I provide a brief analysis of these issues and concerns. But before examining the literature on the use of educational technologies, I will begin with a broader discussion of the overall goals for teaching science and look at some general conditions for learning in classroom settings.

Goals for Science in the Classroom

Helping all students achieve a degree of scientific literacy is a major goal of current national reform efforts in science education (American Association for the Advancement of Science, 1993; American Association for the Advancement of Science: Project 2061, 1993; National Research Council, 1996). *Science for All Americans* (American Association for the Advancement of Science, 1993) outlined several important components of scientific literacy. These include: an understanding of the key concepts and principles of science; familiarity with the natural world in both its diversity and unity; an awareness that science, mathematics, and technology are interdependent human enterprises with strengths and limitations; and the ability to use scientific knowledge and ways of thinking for decision making regarding science-related individual and social issues. Achieving the reform vision for K-12 science education entails pedagogical approaches and instructional practices that are quite different from those which currently characterize science teaching in the majority of K-12 classrooms (National Research Council, 1996). These traditional approaches, which "emphasize the learning of answers more than the exploration of questions, memory at the expense of critical thought, bits and pieces of information instead of understandings in context, recitation over argument, reading in lieu of doing"(American Association for the Advancement of Science, 1993), might even stand as obstacles to achieving scientific literacy for all students. Instead, contemporary reform documents envision science teaching that is inquiry-based, collaborative, and aimed at independent sense making of natural phenomena (National Research Council, 1996).

Conditions for Learning

It is worthwhile to briefly examine the concepts of effective learning in today's classrooms. Beyond the tradition of instructing the fixed facts of the academic disciplines and received knowledge, schools must now enable students to appreciate the complexities of their lives. Children must develop sophisticated interpretation skills, tolerance for uncertainty and ambiguity, an appetite for challenging problems, and measured thoughtfulness in pursuit of solutions. Teachers must guide students in creating habits of seeking out varied perspectives and consulting multiple disciplines for learning's 'big questions.' Modern education requires facility with tools that help to find and make sense of evidence. It requires openness to conversation and collaboration as a way to challenge one's assumptions, and a habit of maintaining interest in new ways of conceiving ideas (Hawkins, 1996).

The sheer amount of knowledge generated in today's world precludes complete 'coverage' by the educational system, "rather, the goal of education is better conceived as helping students develop the intellectual tools and learning strategies needed to acquire the knowledge that allows people to think productively about history, science and technology, social phenomena, mathematics, and the arts" (Bransford, Brown, & Cocking, 2000, p. 5). Cognitive research in the last century has determined that students learn best when four basic characteristics are present: a) active engagement in learning tasks, b) collaboration in groups, c) frequent interaction and feedback from the teacher, and d) connections to real world contexts (Roschelle, Pea, Hoadley, Gordin, & Means, 2000). The structure and resources of traditional classrooms often do not provide these characteristics, while a technology-enhanced environment *can* enable ways of teaching that are better matched to how students learn. "Technology may afford an opportunity for deeper cognitive processing & more authentic science learning..." (Pedretti, Mayer-Smith, & Woodrow, 1998, p. 586), but its presence does not mean it happens automatically (Dexter, Anderson, & Becker, 1999).

Technology in the Classroom: A Brief History

Researchers, developers, and educators have been seeking to define the best roles and functions for electronic technologies in educational settings since computers first began appearing in schools in the mid-1960s (Cuban, 1986). This decade brought computer-assisted instruction (CAI) and computer-based instruction (CBI) to the classroom, providing individualized drill and practice to reinforce basic skills (Culp, Hawkins, & Honey, 1999). Microcomputers became available in the late 1970s, and programs such as LOGO were developed to teach children about computer programming and learning by experimentation (Papert, 1980). With the development and increased availability of lower-cost personal computers in the early 1980s, school use of technology broadened to include applications such as word processing, spreadsheets, and distance learning via two-way audio and video (Shields & Behrman, 2000). However, there was still little learning-appropriate software available for school use. By the mid-1980s, more innovative applications, such as Intelligent Tutoring Systems (ITS) (Schacter & Fagnano, 1999), and interactive multimedia materials (e.g., *Voyage of the Mimi* laser discs) became available. In the 1990s, even more sophisticated applications, including multimedia educational software and the communication features of the Internet and World Wide Web, began to be used to enrich curricula across the range of academic subjects. The combination of computation, connectivity, visual and multimedia capacities, miniaturization, and speed radically changed the *potential* for technologies in education; making possible the production of powerful, linked technologies that can address some of the problems of education (Culp, Hawkins, & Honey, 1999). These challenges include deficiencies in: a) context for classroom learning; b) exploration of 'real world' issues; c) depth of curricular exploration; d) links between subject areas; and e) potential for individualized learning. In this first decade of the 2000s, technology has yet to be universally embraced as a tool to transform how and what children learn in the typical classroom (Shields & Behrman, 2000).

Two Approaches to Technology Use in Schools

There are two major approaches to using technology in schools, learning "from" technology, and learning "with" technology (Jonassen, 2000; Jonassen, Carr, & Yueh, 1998; Jonassen, Howland, Moore, & Marra, 2003; Reeves, 1998; Ringstaff & Kelley, 2002; Salomon, Perkins, & Globerson, 1991). Learning "from" computers takes a variety of forms, including the aforementioned computer-based instruction (CBI), computer-assisted instruction (CAI), Integrated Learning Systems (ILS), and Intelligent Tutoring Systems (ITS). All of these involve using the computer as a tutor. Learning "with" computers (or technology) involves students using technology to gather, organize, and analyze information, and using the information to solve problems (Reeves, 1998). Also, a small percentage of students learn "about" computers and how they work, leading to computer literacy (Jonassen, 2000).

Learning " from" Technology

From the beginning of educational computing, a primary use of computers has been to deliver computer-assisted instruction (CAI), computer-based instruction (CBI), and more recently, more sophisticated programs such as Intelligent Learning Systems (ILS) and Intelligent Tutoring Systems (ITS). These represent learning "from" computers, where the computer is programmed to teach students, and to direct learner activities toward acquisition of predetermined skills or knowledge (Jonassen, 2000). The instructional processes common to all of these tutoring approaches can be reduced to a series of simple steps:

1. exposing students to messages encoded in, and delivered by, technology;
2. assuming that students perceive and encode these messages;
3. requiring a response to indicate that messages have been received, and
4. providing feedback as to the adequacy of the response (Reeves, 1998, p. 2).

The most prominent forms of CAI in the 1970s and 1980s were drill and practice programs. These programs were originally developed in the 1960s to drill, tutor, and test students, while also managing the instructional program for the teacher. The goals were to decrease costs, supplement or replace conventional teaching methods, increase interaction for students, and perhaps to eventually provide personal tutors for all students (Kulik & Kulik, 1991).

With the increasing power and speed of school computers, CAI and CBI have evolved into the more sophisticated ILS and ITS programs. An ILS is a system that includes both courseware and management software running on a computer network (Kulik, 2003). According to Bailey (1992), there are five characteristics of an ILS:

- specifies instructional objectives and ties these to individual lessons,
- provides for lesson integration into the standard curriculum,
- spans several grade levels in one or more curriculum areas,
- runs on a network of computers, and
- collects and records results of student performance.

Some examples of ILS used in U.S. schools today are Odyssey Science[2] from CompassLearning, and KnowledgeBox[3] from Pearson Digital Learning. By the early 1990s, at least a quarter of schools in the United States were estimated to use ILS (Bailey, 1992). Using computers in a tutorial capacity can increase students' basic skills (Kulik & Kulik, 1991), though evaluation specifics will be examined later in this chapter.

Learning "with" Technology

Now I turn to a more lengthy discussion of learning "with" technology. I will spend more time here, as this is where the powerful uses of educational technology lie. In addition, it is in this area that most activities in the Bayview research setting took place.

Many researchers investigating the use of computers in education have reported that technology is most powerful when used as a tool for problem solving, conceptual development, and critical thinking (Culp, Hawkins, & Honey, 1999; Means, 1994; Ringstaff & Kelley, 2002; Sandholtz, Ringstaff, & Dwyer, 1997). In learning "with" technology, "the

[2] CompassLearning information at http://www.compasslearning.com/curriculum/science.asp
[3] KnowledgeBox information at http://www.pearsondigital.com/knowledgebox/

technology is used as a tool, and teachers and students (not the technology) control the curriculum and instruction" (Ringstaff & Kelley, 2002, p. 5). Learning **with** computers supports knowledge construction, explorations, learning by doing, learning by conversing, and learning by reflecting as intellectual partners (Jonassen, 2000). This approach is also known as using cognitive tools (Reeves, 1998; Ringstaff & Kelley, 2002; Salomon, Perkins, & Globerson, 1991), or Mindtools (Jonassen, 2000; Jonassen, Carr, & Yueh, 1998; Jonassen, Howland, Moore, & Marra, 2003).

Cognitive tools

Computer-based cognitive tools have been intentionally developed or adapted to function as intellectual partners to enable and facilitate higher order learning and critical thinking. Examples of cognitive tools include spreadsheets, databases, expert systems, semantic networks, communications software such as tele/videoconferencing programs, on-line collaborative knowledge construction environments, hyper/multimedia construction software, and computer programming languages. In the cognitive tools approach, technologies are given directly to learners, who then function as designers using technology as a tool for analyzing the world, accessing and interpreting information, organizing personal knowledge, and representing what they know to others (Reeves, 1998).

Reeves (1998) also provides these foundations for the use of software as cognitive tools:

- Cognitive tools will have their greatest effectiveness when they are applied within constructivist learning environments.
- Cognitive tools empower learners to design their own representations of knowledge rather than absorbing representations preconceived by others.

- Cognitive tools can be used to support the deep reflective thinking that is necessary for meaningful learning.
- Cognitive tools enable mindful, challenging learning rather than the effortless learning promised, but rarely realized by other instructional innovations.
- The source of the tasks and/or problems to which cognitive tools are applied should be learners, guided by teachers and other learning environment resources.
- Ideally, these tasks and/or problems will be situated in realistic contexts with results that are personally meaningful for learners.
- Using multimedia construction programs as cognitive tools engages many skills in learners such as: project management skills, research skills, organization and representation skills, presentation skills, and reflection skills.

These cognitive tools allow learners to 'off-load' mental tasks, such as memorization of data, to an external resource, the computer, thereby creating an intellectual partnership, in which each partner is responsible for the aspect of learning for which he/she/it is best-suited. Such a development requires a new conception of ability as an intellectual partnership between learners and the tools they choose to use (Salomon, Perkins, & Globerson, 1991). In the specific science context, computers can do more than record laboratory data. The research of Linn, Davis, and Bell (2004), shows that educational technology can "support inquiry projects by providing guidance, collaborative supports, real-time display of data, online interactions with experts, analytic tools, visualizations, simulations, and access to information through databases or websites" (p. xx).

Mindtools

David Jonassen (Jonassen, 2000; Jonassen, Carr, & Yueh, 1998; Jonassen, Howland, Moore, & Marra, 2003) would be considered the main proponent of the concept of

Mindtools, which is really another term for learning with computers as cognitive tools and intellectual partners. These Mindtools engage learners in critical thinking about the content they are studying (Jonassen, Carr, & Yueh, 1998), while scaffolding reasoning about that content. Mindtools are classified into five categories:

1. Semantic organization tools, such as databases and concept mapping tools;
2. Dynamic modeling tools, such as spreadsheets, expert systems, systems modeling tools, microworlds, and visualization tools;
3. Information interpretation tools, such as search engines and visualization tools;
4. Knowledge construction tools, such as hypermedia and multimedia programs; and
5. Conversation and collaboration tools, such as e-mail, chat rooms, and videoconferencing software.

In a nutshell, Mindtools are "computer-based tools and learning environments that have been adapted or developed to function as intellectual partners with the learner in order to engage and facilitate critical thinking and higher order learning" (Jonassen, Carr, & Yueh, 1998, p. 9).

How are Computers being used in the Elementary Classroom?

In the last twenty years, there has been an especially rapid infusion of technologies in elementary science classrooms. Mistler-Jackson and Songer (2000) argue that using research or analysis tools utilized by professional scientists provides students with an opportunity to engage in authentic inquiry. Such engagement enables students to achieve the previously mentioned goals advocated by current science education reform documents.

Here I shall briefly outline some of the specific applications for computers in the elementary classroom, using Jonassen's Mindtools classifications. This is not intended to be an exhaustive treatment, but rather an exploration of a few examples.

Semantic Organization Tools

Semantic organization tools help learners organize and analyze what they know and what they're learning. Students may interrelate ideas, label relationships between concepts, and describe the nature of relationships between all ideas in a network. Examples of semantic tools are databases (such as FileMaker Pro) and concept mapping tools (such as Inspiration).

Database management software was originally developed as a record keeping system, or electronic filing cabinet. Databases are used as tools to analyze and organize subject matter. Constructing a content database requires a learner to develop a data structure, locate relevant information, place it in suitable fields and records, and search and sort the database to answer content-related questions (Jonassen, Carr, & Yueh, 1998).

Semantic networking tools provide visual instruments for making concept maps. A concept map requires that the learner make a visual representation of ideas and how they are linked together. A computer program such as Inspiration, or Kidspiration for younger students, allows the learner to interrelate ideas in multidimensional concept networks, and to label the relationships between them.[4] The purpose of a semantic network is to represent a structure of knowledge that a learner has constructed, which requires analysis of the relationships between studied content. By comparing concept maps made at different times, a teacher may find them useful as assessment tools.

Dynamic Modeling Tools

Dynamic modeling tools allow the learner to express the dynamic relationships among ideas. These can include spreadsheets, systems modeling tools, microworlds, and expert systems and tend to be more appropriate at the upper elementary level and beyond.

---

[4] For example, I used Inspiration software to help me to organize the wide array of concepts needed to write this dissertation.

Spreadsheet software (such as Excel), was originally developed as a business and accounting tool. In education, students can enter a variety of data in a spreadsheet, generate graphs, change data parameters, and answer questions about how changing one variable can affect others. Spreadsheet software models the mathematical logic implied by calculations, which can help the learner to understand the interrelationships and procedures (Jonassen, Carr, & Yueh, 1998). The most common application of spreadsheets at the elementary level is for construction of graphs from input data, such as weather conditions, or planetary statistics.

Systems modeling tools allow the learner to develop sophisticated mental representations of studied phenomena. Examples include Model-It and STELLA, which is a tool for building simulations of dynamic systems and processes. An example of a STELLA-type software utilized in the research classroom is the Starry Night program,[5] which allows learners to construct astronomical models and make comparisons.

Microworlds contain constrained simulations of real-world phenomena that allow the learner to control those phenomena. The learner can navigate, manipulate or create objects, and test their effects on one another (Jonassen, Carr, & Yueh, 1998). An example of a microworld software would be any of those in the 'Sim' family, for example SimEarth, or SimCity. In addition, the older Logo programming language has been adapted into a LEGO/Logo application, which integrates the building block toy set with computer-controlled devices programmed and operated by students (Reeves, 1998). Another modern application is StarLogo, "a programmable modeling environment for exploring the workings of decentralized systems -- systems that are organized without an organizer, coordinated without a coordinator" ("StarLogo on the Web"). With StarLogo, you can model (and gain

[5] Information about Starry Night software can be found at http://www.starrynight.com/

insights into) many real-life phenomena, such as bird flocks, traffic jams, ant colonies, and market economies.[6]

Information Interpretation Tools

Information interpretation tools help the learner to access and process the growing volume of information available. Examples include search engines for use on the World Wide Web, and also visualization tools.

Search engines are vital for a controlled and productive search for information on the Web. However, it can be difficult for children to construct and execute focused searches for information. Many educators have turned to WebQuests in order to guide and facilitate Web research for students. A WebQuest is "an inquiry-oriented activity in which teachers choose Web resources for students to use as information sources in activities designed to support analysis, evaluation, and synthesis of information" (Jonassen, Howland, Moore, & Marra, 2003, p. 44). WebQuests are designed to make effective use of the learner's time, with the goal being to extend and refine knowledge about a topic (Dutt-Doner, Wilmer, Stevens, & Hartmann, 2000). WebQuests can be created by an individual teacher, which can be a time-consuming endeavor. In addition, a wide variety of those created by others are available on the Web. A good WebQuest will incorporate cooperative learning, analysis and synthesis of information, the consideration of multiple perspectives, and the creation of original products that demonstrate gained knowledge (Jonassen, Howland, Moore, & Marra, 2003). Benefits of WebQuests include:

- can be a relatively easy way to integrate technology into existing curricula;
- learners focus on using information rather than searching for it;

[6] StarLogo applications can be found at http://education.mit.edu/starlogo/

- learners' thinking in depth is supported at the level of analysis, synthesis, and evaluation;
- students access and share a wider array of information; and
- students become more familiar with the Web and how to find quality information (Dutt-Doner, Wilmer, Stevens, & Hartmann, 2000).

In this research project, the classroom teacher and I decided not to use WebQuests for three reasons. First, at that time we were unable to find any created by others which satisfied our needs. Second, we did not have time to construct appropriate ones about our topics. Lastly, we decided that with our support, we wanted students to gain experience and skill searching for information on their own.

Visualization tools help students represent and convey mental images, often using very content-specific programs. For example, Spartan[7] and ChemViz[8] allow the (secondary) learner to visualize how matter interacts at the atomic level, e.g., bonding. There are fewer visualization software packages available for younger learners, though one mentioned in the previous category would fit here as well. Starry Night allows the learner to view models of the night sky, solar system, and lunar phases, which can aid in the comprehension of somewhat abstract concepts.

Knowledge Construction Tools

Knowledge construction tools include multimedia, desktop publishing, hypertext, web site construction and html editing, CD-ROMs, and other related technologies (Jonassen, 2000). Jonassen continues by stating that these can also be classified as hypermedia; with

---

[7] More information about Spartan can be found at http://www.wavefun.com/

[8] More information about ChemViz can be found at http://chemviz.ncsa.uiuc.edu/

hypermedia defined as "structured, interconnected multimedia knowledge bases that use all of these technologies" (Jonassen, 2000, p. 205).

Jonassen bases this category of Mindtool on the concept of constructionism as defined by Papert. Constructionism is described as the process of knowledge construction resulting from constructing artifacts. Designing objects allows learners to construct knowledge more naturally and completely than they would by studying about them. This approach is different from knowledge reproduction activities, but rather complements the pedagogical tenets of constructivism, as knowledge is built by the learner, not supplied by the teacher.

When constructing hypermedia, learners are actively engaged in perceiving different perspectives and organizing their own representations to reflect their understanding of concepts. Hypermedia projects can grow and change at the direction of the user/learner. Constructing a hypermedia or multimedia presentation encourages the learner to use their project management, research, organization, representation, presentation, and reflection skills. A specific example of this type of application is Video Paper Builder,[9] which allows students to construct their own multimedia web page. In this particular research project, PowerPoint files created by the Bayview students served in this capacity as well.

Conversation and Collaboration Tools

Jonassen's last category of Mindtool is the conversation, or collaboration, tool. This tool is based upon the concept of learning as the dynamic interplay between the activities that people engage in and the sense of that activity that is socially negotiated (Jonassen, 2000). These tools include both synchronous and asynchronous computer-supported environments,

[9] Information about Video paper Builder can be found at http://vpb.concord.org/

such as videoconferencing, online chats with content experts or practitioners, instant messaging, e-mail, discussion boards such as Blackboard and WebCT, Moodle, listervs, etc. These forms of telecommunications can be used for supporting interpersonal exchanges among students, collecting information, and solving problems in groups. This category was not heavily used in the Bayview project, as e-mail was the only form of this tool available.

Issues and Problems associated with the use of Computers in the Elementary Classroom

With the widespread adoption of computers and related technology in classrooms come various concerns that must be addressed. In educational technology research, "there is a conspicuous lack of attention to the complexities and intricacies of how classroom teachers actually incorporate technology in their teaching" (Zhao, Pugh, Sheldon, & Byers, 2002, p. 483). This is especially true for the *elementary* science classroom. However, one team at the University of British Columbia has done extensive work with *secondary* science teachers in the Technology Enhanced Secondary Science Instruction (TESSI) project. In 1992, TESSI began as a partnership between secondary science teachers and university researchers who wished to explore how technology could be used to enhance teaching and learning (Mayer-Smith, Pedretti, & Woodrow, 1998a, 1998b; Woodrow, Mayer-Smith, & Pedretti, 1996, 2000). Originally begun with one researcher teamed with two teachers in two schools, TESSI grew to include three researchers and seven teachers in six schools, with an expansion of the model to schools in Mexico. Ultimately, TESSI's results show how teachers acting as agents of technological change in their science classrooms can drive pedagogical innovation and professional development (Pedretti, Mayer-Smith, & Woodrow, 1999).

Roschelle et al. (2000) delineate the conditions necessary for effective technology use in the classroom:

- access and technical support,

- defined instructional vision and rationale linked to technology use,
- critical mass of teachers involved in technology activities,
- high degree of teacher collaboration,
- strong leaders,
- support for teacher time to collaborate, plan, and reflect/report on technology use,
- location of computers; i.e., in classrooms or labs,
- teacher computer expertise,
- teacher philosophy and objectives, and
- school culture.

This is an extensive list, and one which I do not intend to fully explore at this point. I shall concentrate only on those which relate to what to me is the fundamental issue; that of change in the classroom due to the influx of technology. Related to this are the issues of:

- classroom ecology,
- change in roles for teacher and students,
- school reform,
- evaluation of technology use and effectiveness in the classroom, and
- increasing emphasis on assessment as it relates to technology use.

A separate, but important concern is that of access to technology in the classroom, which I briefly explore before turning to the larger matters of classroom change and the above set of issues.

Access to Technology

Without sufficient access to technology, even well trained, highly motivated teachers will not be able to integrate technology effectively into instruction. Although studies are inconclusive about the optimal number of computers per classroom (Mann, 1999; Ringstaff

& Kelley, 2002), research is clear that students and teachers are best served if they have convenient, consistent, and frequent access to technology (Mayer-Smith, Pedretti, & Woodrow, 1998b; Pedretti, Mayer-Smith, & Woodrow, 1999). Some research has shown that the distributed model, with computers located in classrooms rather than in dedicated computer labs, is the most effective (Ringstaff & Kelley, 2002).

Each year, *Education Week* publishes an issue entitled "Technology Counts," which provides general data about instructional technology use in schools across the United States. In 2002 (the year of my research), the ratio of all students per instructional computer in the United States was 3.8:1. In high-poverty schools, that ratio was 4.0:1, and in high-minority schools 4.1:1 ("Technology Counts "). This is an improvement from previous years, but does not take into account other factors, such as age of the computers, or multimedia capabilities. The ratio of students per Internet-connected computer was 5.6:1 for all students; 6.3:1 for high-poverty schools; and 6.7:1 for high-minority schools. However, that ratio includes all computers in a school, not just those available for instructional use. Even though these numbers are tracking in a favorable direction, many teachers continue to report that lack of access is a significant barrier to technology integration (Ringstaff & Kelley, 2002). The discrepancies in the ratios in the general population and those in high poverty and minority schools are known as the *Digital Divide*, which is of concern in many educational circles.

Classroom Ecology

Classrooms are complex dynamic environments that feature a range of multi-faceted interactions between a variety of social agents and artifacts embedded in a larger cultural milieu. Classroom ecology comprises interactions between teachers, students, curricular materials, pedagogical and assessment practices, and tools and techniques, as mediated by the underlying premises of the artifacts, attitudes, perceptions, and beliefs of the social agents

(Edelson, 1998; Minstrell, 1996). Classroom culture has a considerable influence on how technology gets used (Reilly, 1996), and the teacher, students, curriculum, pedagogy, technology, and the social nature of the classroom are highly and intricately related (Salomon, Perkins, & Globerson, 1991).

Apple (1998) argues that the complexity of classrooms is often overlooked when technology is viewed as having a life of its own, independent of social intentions, power, and privilege. Technology should be viewed as another component of classroom ecology that affects and is affected by all other components. In a typical classroom, technology can work as a selective force marking its participants as full, marginal, or non-participating, by mere default of economic status, academic success, previous exposure to technology, and numerous other factors (Apple, 1998). From the classroom ecology perspective, it is how technology is used and interacts with the classroom ecology that is important, not what technology is in place (Pedretti, Mayer-Smith, & Woodrow, 1998).

Change in Roles in the Classroom: Student and Teacher

The introduction of technology can impact the classroom and the roles played by its members. Technology can place students in a more active role, which forces new relationships between the teacher and students (Cuban, 1998; David, 1996). Though the teacher has an essential responsibility in determining what gets done and who does it (Reilly, 1996), often the teacher's role shifts from dispensing knowledge to helping learners construct more viable conceptions of the world as they engage in the larger community of scholars (Jonassen, Howland, Moore, & Marra, 2003; Mayer-Smith, Pedretti, & Woodrow, 1998b). The teacher may become more of a 'guide on the side,' rather than the 'sage on the stage.' Learning is defined as a reflective, personal, and transformative process, in which teacher work is seen as facilitating students' abilities to integrate ideas, experiences, and points of view into something new (Dwyer, 1996).

Pedagogically, when a number of computers are introduced into a classroom, there is often a move from whole group to small group and individual instruction, along with increases in student collaboration and cooperation, peer teaching, and student regulation of learning (Becker & Ravitz, 1999). The focus may move from a teacher in the front of the room to students working together in groups, giving students the opportunity to interact, provide assistance, and share ideas with each other (Mayer-Smith, Pedretti, & Woodrow, 1998b; Tierney, 1996). The role of computers in promoting social relationships is further supported by the observation that children usually turn to each other, rather than to an adult, for computing advice, even if an adult is available (Wartella & Jennings, 2000). Students may take on the roles of demonstrator, partner, helper, sounding board for new ideas, advisor, mediator, supervisor, and decision maker (Tierney, 1996). Students may engage in more self-questioning as they become experts who take active responsibility for their own learning (Sandholtz & Ringstaff, 1996).

Teachers may use technology to enhance their previous instructional practices, such as using multimedia for demonstrations, but it takes considerable time and skill before they can help students to exploit technology's benefits as a tool (Marx, Blumenfeld, Krajcik, & Soloway, 1997). Teachers need more than a year or two to explore all options of how to successfully integrate technology into instruction (Mayer-Smith, Pedretti, & Woodrow, 1998b), and may even experience regressions to previous more teacher-centered methods (Sandholtz & Ringstaff, 1996). However, technology can serve as a symbol for change, granting teachers a license for experimentation (Ringstaff & Kelley, 2002).

It has been found that teachers who are computer users exhibit constructivist practice, including collaboration, project-based work, and hands-on activities (Honey & Moeller, 1990). Computers facilitate these activities, but were teachers who used the computers more likely to be constructivist in the beginning? It has also been reported that constructivist-oriented teachers use computers in more varied and powerful ways, have greater technical expertise in their use, and use computers frequently with students (Becker, 2000). According to Ringstaff and Kelley (2002), "...compared to more didactic approaches, constructivist or student-centered approaches are better suited to fully realize the potential of computer-based technology" (p. 2) and, "more advanced uses of technology support the constructivist view of learning in which the teacher is a facilitator of learning rather than the classroom's only source of knowledge"(p. 9).

School Reform

The incredible rate of change of technology contrasts sharply with the more stately pace of change in K-12 education, a contrast that creates challenges and opportunities (Smith & Broom, 2003). The question becomes, will technology support and amplify conventional classroom practice or will it have a transformative effect? Unless our thinking about education is transformed along with our continuing expansion of technology into the classroom, the investment in technology will fail to measure up to its potential (Thornburg, 2000a).

Most decisions to make technology available in the classroom originate at the school, district, or state level, so it is important to understand the school system as a hierarchical organization within which technology and curriculum exist (O'Dwyer, Russell, & Bebell, 2004). This situation can exist alongside the complex and emergent system of a classroom, as I shall explore more fully in the next chapter. In addition, Roschelle et al. (2000) state "research indicates...that the use of technology as an effective learning tool is more likely to take place when embedded in a broader education reform movement that includes improvements in teacher training, curriculum, student assessment, and a school's capacity for change" (p. 76). Unfortunately, many technology purchase decisions are made without fully planning for implementation and integration. Research suggests that technology projects should be implemented only after a planning stage, in which all stakeholders develop clearly articulated goals and standards for technology use (Ringstaff & Kelley, 2002). In addition, the technology must be integrated into the curricular framework.

When change happens in a school, teachers must confront their beliefs about learning and teaching. The introduction of technology can provide the catalyst for this examination of practice and learning goals (Dwyer, Ringstaff, & Sandholtz, 1991). For example, in the TESSI project, the science teachers did not consider the computers to be a substitute for their presence, but rather as a way to enhance and transform their practice (Mayer-Smith, Pedretti, & Woodrow, 1998a). However, the availability of technology alone cannot do much to compel change. Instead, to raise student achievement, technology use should be supported by other improvement efforts, such as sufficient technical support, teacher technology training, and long-term planning (Mayer-Smith, Pedretti, & Woodrow, 1998b; McCabe & Skinner, 2003).

Evaluation of Technology Use and Effectiveness in the Classroom

The effective use of technology in education requires thought, experimentation, and a willingness to spend the time needed to develop and refine strategies until they are proven to be effective. Patience is important; it takes time to see results (Thornburg, 2000b). This can be difficult in the pressure-filled world of evaluation of educational practice. Evaluation difficulty also arises in technology projects as many important consequences, and new patterns in complex teaching and learning practices will emerge rather than be preordained or designed at the outset (Baker, Hermann, & Gearhart, 1996; Dwyer, Ringstaff, & Sandholtz, 1991).

A good study of student learning in a technology-rich context needs to focus less on establishing that these situations are 'better' than non-technological situations, and more on establishing two ideas: first, that the technology-rich context makes possible something different than what would be possible without technology, and second, that students can and do succeed in learning the concepts the technology-rich situation is designed to help them learn (Culp, Hawkins, & Honey, 1999). The point of using technology, developers and proponents argue, is not to do what we have always done *electronically*, but rather to provide kinds of learning experiences that are impossible to provide in any other way (Means, Haertel, & Moses, 2003).

It is clear that no one study will answer all the critical questions. The process of evaluation is not easy, given the many different purposes for which various technologies are used and the complexity of fully integrating technology into teaching and learning (Haertel & Means, 2003). A serious investigation of the impacts of educational technology on student learning requires multiple studies and more than one methodological approach (Means, Haertel, & Moses, 2003). An interesting question is brought up by McCabe and Skinner (2003); would we wonder whether pencils, chalkboards, etc., have a positive effect on student learning? Should computer technology be thought of in that way, as a mere tool, rather than in a curricular fashion? In some applications, such as word processing, computers may be seen as only tools which may improve the writing process, but not radically change instruction. In my research, computers were used in this fashion, but additionally as an avenue to tremendous amounts of information, which was then interpreted, organized, and presented to peers. In actuality, even with this enriching experience, we still did not exploit the full potential of these tools.

Some studies show use of higher order computer applications increases student learning, and computer-based instruction, or 'drill and kill' programs decrease performance. For example, Wenglinsky (1998), in work based upon data gathered from the 1996 National Assessment of Educational Progress (NAEP) in mathematics, found that teacher's professional development in technology and the use of computers to teach higher-order thinking skills were both positively related to academic achievement in mathematics for 8th graders. Other studies, such as a meta-analysis of 254 controlled evaluation studies from Kulik and Kulik (1991), have shown that computer-based instruction (CBI), or 'drill and kill' applications, increased student achievement. Why the mixed results? These can be partially explained by timing, as the Kulik and Kulik work is substantially older. In fact later meta-analysis work from James Kulik (2003) found that newer studies showed increased use of ILS applications in classrooms, in addition to productivity tools, which then correlated with increased achievement. Roschelle et al. (2000) give three additional reasons for disparity in findings:

1. Variation in hardware and software and how it is *used* in schools,
2. Other changes may happen concurrently with technology introduction and have an effect, and
3. Rigorously structured longitudinal studies that document isolated effects of technology are expensive and difficult to implement, so few are done.

Long term unintended effects and short-term focused and intended effects are not always neatly separated (Salomon, 2000). Salomon continues by discussing why he thinks computers have not really changed formal education. First is the idea of the technological paradox, in which education "domesticates" new technology into existing practice; or "fits (it) into the prevailing educational philosophy of cultural transmission" (p. 3). Computer applications are then seen as useful for drill and practice, or learning “from” rather than “with”. “These emasculated tools cannot do any harm, but they do not do any good either" (p. 3). Second is the technocentric focus, in which instructional technology is seen as that which will replace the teacher. Then, “it is the technology that needs to be mastered as an end in itself, not as a means for the acquisition of something such as knowledge or social skill" (p. 4). Technology is a far more tempting object than a new approach to learning, which can help with information, but not with knowledge. Third, Salomon addresses misguided research, i.e., the ‘horserace approach.’ In this variety of research, the question is, ‘does x produce better learning results than y’? This completely disregards complex aspects of the classroom, such as attitudes, tasks, contents, and contexts. Again, it is the context which can confound technology research. Pedagogy and content are usually confounded with the use of technology, so that comparative studies examine the differential effects of the package, rather than of technology by itself (Means, Haertel, & Moses, 2003).

In order to do good technology research, regardless of sample size and the range of implementation contexts included in the study, features of the context need to be documented carefully. If not, it is hard to accumulate findings across studies or to know if generalization is possible. In order to evaluate in context, student population, software design, the educator's role, how students are grouped, the preparedness of the teacher, and the level of student access to technology should be taken into account. A match is needed between the goals of instruction, characteristics of learners, design of software and technology implementation decisions (SIIA, 2000). This context may be a traditional classroom, in which highly structured tutoring applications may be effective. Or, in a more constructivist atmosphere, "most learning and technology researchers would argue that Web based collaborative technologies, authoring and programming applications, intelligent tutoring systems, simulations, modeling programs, and productivity tools provide a richer computer environment for learning" (Schacter & Fagnano, 1999, p. 332). Lastly, it has been suggested that rapid growth and improvement in technological tools exceeds current knowledge of how to effectively use these tools in schools, therefore the impact of technology may be different today than was found in past studies (Waxman, Connell, & Gray, 2002).

Assessments and Technology Use

Reeves (1998) states that computers as tutors have positive effects on learning as measured by standardized tests, are more motivating for students, are accepted by more teachers than other technologies, and are more widely supported by administrators, parents, politicians, and the public. However, standardized tests are not the best way to study the effects of any educational innovation, including technology (Lesgold, 2003). There is a mismatch between the content of district and state assessments and the kinds of higher order learning supported most effectively by technology. New assessments are needed to reflect the contribution of technologies in developing students' abilities to reason and understand concepts (Roschelle, Pea, Hoadley, Gordin, & Means, 2000). Measuring the same skills and goals from a time without a technology presence doesn't make sense. As Salomon (2000) states, "(w)hat technology does or fails to do in education depends far less on what it can do and far more on what education allows it to do" (p. 8).

While technology may make learning easier, efficient, and more motivating, ease and efficiency are not prerequisite conditions for deep and meaningful learning. Learning is not always easy or efficient. It is important that educators and policy makers understand and recognize the intricate nature of technology's impact on student outcomes (Schacter &

Fagnano, 1999). Many standardized assessments don't adequately measure skills that technology enhances, such as critical thinking, other higher order thinking skills, and problem solving. Studies that rely on standardized assessments are therefore inconclusive (Ringstaff & Kelley, 2002). Few reliable, valid, and cost-effective assessments exist that measure students' higher order thinking skills, problem solving ability, or capacity to locate, evaluate, and use information—skills that many teachers and researchers believe can be enhanced through the use of technology.

Teacher Professional Development and Technology

While there is a large body of research on effective models of staff development for teachers (e.g.,Guskey & Huberman, 1995; Killion, 1999; National Staff Development Council, 2001), the research on effective professional development models designed to change teacher practice with respect to *technology integration* is in its infancy. The research that does exist on effective staff development for teachers has not always filtered into the actual design of those activities. The one shot approach, or even one shot plus follow-up, has not been shown to be effective (International Society for Technology in Education, 2000, 2002; Sandholtz, Ringstaff, & Dwyer, 1997; Schrum, 1999) and yet persists. In the case of technology, the all too common approach of providing "... motivational speeches by a forward-looking visionary plus sessions on how to use a piece of software" in the hopes that teachers will develop "... some technical skills and a good attitude" (Zhao, Pugh, Sheldon, & Byers, 2002, p. 511) is simply not enough.

Teachers must have ample time in order to acquire, and then transfer the skills and knowledge needed to effectively infuse technology into their teaching (Brand, 1998). Brief exposure does not provide sufficient training or practice to incorporate technology into a classroom (Schrum, 1999). It is estimated that more than 30 hours of training and experience are necessary to see *adoption* of new technologies, with far more needed for actual implementation and integration (Mehlinger, 1997). The amount of time each teacher needs will vary, but it must be enough to allow for exploratory learning and experimentation (Brand, 1998; Sparks, 1998).

In general, professional development is provided for groups of teachers via a school, district, or regional administration of some kind. Teachers have varying needs and abilities in technology, which should be addressed with flexible professional development opportunities (Brand, 1998). These can be provided outside of the school or on-site, in large or small groups, or individually. This flexibility can address some of the difficulties which can occur with "just in case" instead of "just in time" learning; for example, teaching a group of teachers how to use a spreadsheet program, just in case they ever want to use it. In contrast, offering participants authentic reasons from their daily teaching to learn about a particular activity might encourage educators to experiment with that type of program (Schrum, 1999).

While some would say that professional development in technology should take place away from the school in order to diminish distractions and allow for the large chunks of time needed by teachers to thoroughly explore new tools (Brand, 1998), others state that the most worthwhile professional development occurs in the more comfortable context of the teacher's own classroom (Pedretti, Mayer-Smith, & Woodrow, 1999). In actuality, it would seem that a mix of experiences is appropriate, tailored to the needs and abilities of each teacher. Sustained and uninterrupted time to understand a new program or piece of equipment is impossible to achieve in a class full of students, but it is difficult to know how a new tool will work in the classroom without eventually using it in that context.

Neither technical skills nor pedagogical knowledge of technology use are likely to be fully integrated into classroom practice without ongoing assistance and continual professional development (Ertmer & Hruskocy, 1999). Administrators can provide this assistance in the form of a reduced teaching load, monetary compensation, release time for training and collaboration, funding for professional conferences, etc. In all professional development experiences, teachers should be encouraged to think first about their educational and curricular objectives, and then about how technology can support those goals. Technology must be seen as relevant to instructional goals, not as an add-on or separate activity (Brand, 1998; Browne & Ritchie, 1991; Mayer-Smith, Pedretti, & Woodrow, 1998a, 1998b; Pedretti, Mayer-Smith, & Woodrow, 1999; Woodrow, Mayer-Smith, & Pedretti, 2000).

Teachers also need support when implementing technology in the classroom, from a technological and curricular perspective. Novice computer users are more likely to integrate technology into their curriculum when they have someone, either at the school or district level, they can turn to for knowledge about computers, but also for emotional support and reassurance (Brand, 1998). Peer coaching and mentoring have been shown to be effective models for addressing the unique needs of individual teachers (Brand, 1998; Franklin & Sessoms, 2006; Thurlow, 1999). In addition, collaborative relationships between classroom teachers and university researchers can provide effective support (Ertmer & Hruskocy, 1999; Pedretti, Mayer-Smith, & Woodrow, 1999).

Teachers need compelling reasons to dramatically change their practice. If change is forced or mandated from administration, the result may be tenuous acceptance, without real change (Evans, 2001; Schrum, 1999). In addition, teachers need to find the professional development and corresponding implementation intellectually and professionally stimulating

(Brand, 1998). Teachers become hooked when they begin to use technology in ways that work within their personal instructional contexts, and see benefits to their students (Sparks, 1998). Ultimately, it is up to the teacher to decide to implement the changes that will accompany integration of technology tools into his/her classroom. They must play a central role in deciding how to implement the integration of technology tools within their classroom context (Kimmel & Deek, 1995; Mayer-Smith, Pedretti, & Woodrow, 1998a).

Concluding Remarks

The use of educational technology in the classroom has changed over the years as equipment and software have become more diverse, advanced, and inexpensive. As the technology changes, so do its uses. As mentioned earlier, it is difficult to evaluate particular pieces of equipment or software as they may become obsolete before such an evaluation is published. In addition, a specific technology component may work very well in a particular educational context, but poorly in a different one. That is why in all educational technology research, including this project, it is important to carefully document contextual parameters of the implementation environment, such as student population, the preparation level of the teacher, access to equipment, how students are grouped, etc.

Computers are here to stay in the elementary classroom. Where the real work lies now is in the area of implementation and integration into the curriculum. How best can technology be used to support learning in the elementary science classroom? Researchers, developers, and educators continue to seek to define the best roles and functions for electronic technologies in educational settings. The role of classroom and school context in educational reform in all areas, including technology, is becoming increasingly apparent. In this era of accountability, it is important to continue with a wide range of research projects examining the impacts of educational technology on learning and achievement.

In this dissertation, I address these very issues of the use of technology in the *elementary* science classroom. How can the imaginative integration of technology tools extend the practices of a teacher and her students; how do teacher and student roles change; what structures support technology integration in the complex classroom? How may a teacher negotiate the process of integrating a potentially disruptive innovation into his/her familiar environment? In this research, an elementary teacher integrates computers into the research process for her 4th and 5th graders as they study astronomy and space exploration. As I mentioned previously, there is little published research in the area of technology use in the elementary science classroom.[10] At a basic level, free and easy access to an adequate number of computers is crucial. My research shows that indeed it is very important that the teacher take the lead and drive the use of technology in the classroom, but also the students must feel free to interact with the technology and each other as they negotiate new ways of learning. In addition, collegial support, in this case provided by me as a participant researcher, is significant.

In my research into the practices of Belinda and her students, I have taken a complex, or ecological approach, while conceptualizing educational technology as cognitive tools, or as Jonassen's Mindtools. Research that explores how a teacher and her students interact with technology tools, science curriculum, and each other is a fruitful mode of inquiry, which can then be applied to other technology tools, rather than focusing on a particular piece of software or equipment. In the next chapter, I will provide a brief summary of complexity theory and its origins, but more specifically explore how complexity concepts apply to the classroom environment.

---

[10] A final search of ERIC on Sept. 3, 2006 using the terms 'educational technology', 'professional development', 'elementary', and 'science' from 1996 to the present yielded 185 results. However, the majority of these do not relate to the use of educational technology in elementary science classrooms, or to professional development in this area.

Chapter Three: Complex Environment of the Classroom

In the previous chapter, I examined educational technology and its role in the classroom. Computer tools and software, like any new idea, action, or individual introduced into the classroom community or system, can lead to dramatically diverse outcomes. This sensitivity to initial conditions is a hallmark of complex systems. For this reason and others that I outline in this chapter and the following methodology chapter, I have chosen to frame my research in the Bayview classroom in the field of complexity theory.

Sumara & Davis (1997) state: "...teaching and research, like all cultural forms, are complex phenomena which resist simplistic reductions or interpretations" (p. 301). This assertion is meant to convey that education is not a simple field in which to operate in any capacity, but rather one that is rich, diverse, fluid, dynamic, organic, and self-organizing. The traditional school environment is one that is ordered, at least on the surface, with its bell schedules; quarter, trimester, and semester calendars; lesson and unit plans; assignments; and tests. But this orderliness ignores the primary component of education environments: people. It is the students, faculty, staff, and other community members along with the interactions among them that create the learning system called school. It is this environment which cannot be thoroughly described in familiar reductionist terms, in which a system is broken down into its component parts in order to discover an explanation for the behavior of the whole (Davies, 1988; Morowitz, 2002).

Historically, this machine or factory model has been applied to the school environment, with students (input) being molded into appropriate citizens of society (output) by the education experience (Tyack & Cuban, 1995). If this model were accurate, that would mean that if only we could determine the optimum way to perform this task of education, and then train all teachers to perform it effectively, schools would then produce well-educated and industrious citizens.

Personally, though familiar, this model has always seemed cold, behaviorist, and inaccurate, with little respect for the human element of school. Learning about the various types of constructivism during my teacher certification program alleviated some of my discomfort, though I found the social aspect of constructivist learning far more interesting than the individual, perhaps due to my training in anthropology as an undergraduate. It is learning about complexity theory and how it relates to the classroom experience that has allowed me to do more extensive thinking about classroom environments.

In the first part of this chapter, I briefly describe complexity theory, its origins in the physical sciences, and eventual adaptation to the social sciences and education. In the latter part of the chapter, I describe the specifics of how complexity theory operated as a lens through which I experienced the Bayview classroom.

Complexity and the natural sciences

The study of complexity, which arose in the natural and philosophical sciences, involves the examination of complex systems that are inherently non-linear, open, and far from equilibrium (Phelps & Hase, 2002; Thelen & Smith, 1994). A non-linear system is unpredictable; if one is familiar with all of the components of the system, one is still unable to determine exactly what will happen next. In a non-linear system, the whole is greater than the sum of its parts (Arthur, 1999; Brodnick & Krafft, 1997; Capra, 1996; Casti, 1994; Davies, 1988; Gallagher & Appenzeller, 1999; Phelps & Hase, 2002; Pigliucci, 2000; Reason & Goodwin, 1999; Sumara & Davis, 1997). A complex system is also open, in that it needs and receives energy to maintain its order. So, complex systems are "open, nonequilibrium systems: open in the sense that they can interact with their environment, exchanging energy, matter or information with their surrounds; and nonequilibrium, in the sense that without such sources they cannot maintain their structure or function" (Kelso, 1995, p. 4).

Complexity science offers something beyond reductionism, as "it understands that much of the world is not machine-like and comprehensible through a cataloguing of its parts; but consists instead mostly of ... holistic systems that are difficult to comprehend by traditional scientific analyses" (Lewin, 1999, p. x). However, each complex system is different, and there are no general laws for complexity as can be determined for the reductionist approach (Goldenfeld & Kadanoff, 1999).

Historically, the study of natural science proceeded within a reductionist framework, which is essentially a strategy of 'divide and conquer:' dividing the natural world into constituent systems whose parts are simple enough to allow prediction of their behavior, and then, hopefully, to control their activity (Reason & Goodwin, 1999). Reductionism can be defined as the procedure of breaking physical systems down into their elementary components, then analyzing them one part at a time, in order to explain the system's behavior via the lowest level (Davies, 1988; Pigliucci, 2000). This linear cause-and-effect metaphor of organization as machine, or the Newtonian/Cartesian perspective, has worked quite well in the physical sciences over time, and to some extent in biology, and has supported the development of modern systems and practices (Brodnick & Krafft, 1997). The approach could be summed up as the belief that the manipulation of the parts of a system results in control over the whole.

However, the limitations of this approach have become more apparent over the last 150 years as scientists have worked to explain the inherent complexities of organisms and ecosystems, patterns of global ecological change, and organizations and societies. In the late 1800s, Henri Poincaré, a French physicist and mathematician, applied the classic Newtonian theory of gravitational attraction to the Sun, Earth, and Moon, and found that even this simple three body system was in a state of dynamical instability, or not inherently predictable in its behavior.[11] Rather, working the equations resulted in a distinct and dynamic model (Reason & Goodwin, 1999). Examining the components did *not* result in completely accurate predictions about the behavior of the system.

In the early 1900s, Lawrence Henderson, a biochemist, began applying the ideas of systems to living organisms and social entities (Capra, 1996). By the 1930s, many key systems characteristics had been formulated. A system was defined as a group of interacting, independent elements that form a complex whole (Brodnick & Krafft, 1997), or an "integrated whole whose essential properties arise from the relationships between its parts" (Capra, 1996, p. 27). Applied to biology, the essential properties of a living system are the properties of the whole. These properties arise from the interactions among the components and are destroyed if the system is dissected into its separate elements (Brodnick & Krafft, 1997; Laidlaw, 2004). Such a system should be studied holistically. Individual parts of the system can be discerned, but they are not isolated, and the nature of the whole is always different than the mere sum of its parts (Capra, 1996; Davies, 1988; Davis & Sumara, 2000; Gallagher & Appenzeller, 1999).

But, what does it mean to be a complex, as opposed to a simple, complicated, or even chaotic system? Weaver (1948; also see Davis & Simmt, 2003) delineated the following three categories:

---

[11] The **"three body problem"** is the solution of the motion of three bodies under their mutual attraction. It is famous for having stymied astronomers for many years, and the king of Sweden even offered a prize to whoever solved it: the prize was claimed by the French mathematician Henri Poincaré, who proved that in general it was insoluble--that no explicit formula existed that predicted the motion for the indefinite future. In today's terminology one would say that the general three-body motion has chaotic properties. Even the general "restricted three body problem" where one of the bodies is very small--e.g. Earth, Moon and spacecraft--is insoluble, although specific solutions exist, like the ones in which the spacecraft is positioned at one of the Lagrangian points. http://www-spof.gsfc.nasa.gov/stargaze/Slagrng2.htm Poincaré is considered to be the founder of chaos theory, with his work on the three body problem.

- **Simple** systems are determinate, with few interacting agents. An example from Newtonian mechanics would be the motion of a single billiard ball, or up to two or three, upon a table. However, without computers (which were on the immediate horizon in Weaver's time), it would become unmanageable to describe the motion of ten or fifteen billiard balls.
- **Disorganized complex** systems (now referred to as **complicated**) are those on a large scale, such as a billion billiard balls, atomic motion, or astronomical phenomena. These are still deterministic, with methods of statistical and probability analysis being enlisted to understand them. For these multivariable systems, basic and inevitable tendencies can be described, but specific behavior of one atom, or a single billiard ball, within a complicated system cannot be reliably predicted.
- **Organized complex** systems are those that Weaver saw as falling between the previous two categories. These are systems which contain a sizable number of factors that are closely interrelated into an organic whole. Examples include viruses, proteins, brain function, and social collectives such as economies or labor unions. Problems in these areas cannot be effectively studied in simplistic or statistical ways, which necessitated the development of complexity science as a field.

Weaver (1948) believed that the advent of computers would allow the development of new methods of analysis applicable to the problems of organized complexity, and he was correct. In addition, the field of complexity science has matured over the past 60 years through the work of researchers in the natural sciences, mathematics, computer science, and the social sciences.

The concepts of chaos and complexity are very closely linked, to the point that some authors will use the terms interchangeably at times. Complex systems are said to exist on the edge of chaos, at the border between rigid order and randomness (Horgan, 1995; Kauffman, 1995); or in a "constantly shifting battle zone between stagnation and anarchy" (Waldrop, 1992, p. 12). What is meant by chaos? Waldrop (1992) refers to chaos as completely formless, but in a scientific context, the word *chaos* has a slightly different meaning than it does in its general usage as a state of confusion, lacking any order. Chaos, with reference to chaos theory, is an apparent lack of order in a system that nevertheless obeys particular laws or rules; this understanding of chaos is synonymous with dynamical instability, a condition that refers to an inherent lack of predictability in some physical systems. The two main components of chaos theory are the ideas that a) systems -- no matter how complex they may be -- rely upon an underlying order; and b) very simple or small systems and events can produce very complex behaviors or events. This latter idea is known as sensitive dependence on initial conditions. In other words, a small change introduced to a complex system initially, can have a great effect later.

In conclusion, these are characteristics of complex systems:

- They are **adaptive**, in that their elements adapt to the world they co-create; as the elements change, so does the aggregate (Arthur, 1999). Complex systems constantly evolve and unfold over time.
- They exist at the **edge of chaos**; if a system is too ordered, it loses flexibility of response (Reason & Goodwin, 1999); if it is too chaotic, it is unable to respond. In order to maintain this optimal position at the edge, the system must be **open**, in that it needs and takes in energy of some sort.
- Complex systems are **emergent** as at each level of complexity, new and unexpected qualities appear, which cannot be predicted through the properties of the component

parts (Davies, 1988). A notable example is the behavior of ant colonies (Johnson, 2001).[12]

- They are **holistic**, as their order emerges due to the interactions between its component parts, and is not determined by a privileged set of components (Reason & Goodwin, 1999). Order is derived from transcendent properties and capacities, not from central organizers or governing structures (Davis & Simmt, 2006). This relates to the **non-linear** aspect of complex systems in that the behavior of the whole cannot be determined by examination of its parts.
- Complex systems exhibit **self-organization** in that their order arises due to the spontaneous interactions of the component parts; organized according to local parameters and self-interest, and without a centralized command structure (Capra, 1996; Doolittle, 2001). Kauffman (1995) calls this 'order for free' as organisms will order themselves spontaneously, with no need to fight entropy to achieve it. Evolutionary theory then must take into account two sources of order in the biosphere, natural selection and self-organization. It is the relations among the components of a complex system, not the components themselves, that are productive, and therefore interesting (Davis & Sumara, 1997).
- Complex systems exhibit **sensitivity to initial conditions**, or the 'butterfly effect,' as defined by Edward Lorenz, an MIT meteorologist attempting to model weather systems using computers in the 1960s. He found that even a small perturbation of a

[12] Another analogy is that of water, or H_2O. The complex properties of water, such as phase transition temperatures, are not derivable from the individual properties of hydrogen and oxygen. Knowing about the structure and behavior of the atoms composing H_2O, allows us to predict water's structure, but not its behavior (with thanks to Pigliucci, 2000, for this example).

complex system can result in large future consequences (Casti, 1994; Iannone, 1995; Pigliucci, 2000; Reason & Goodwin, 1999).[13] Small changes can have large effects.

Complexity and the social sciences

More recently, complexity theory has been applied in the context of social sciences, which by definition involves people. These human agents, who are themselves complex systems, react with foresight and strategy, considering outcomes that may result as a consequence of any behavior they may undertake (Arthur, 1999). This makes the study of complexity in this context very different from what happens in the study of the natural sciences.

Beginning in the 1980s, researchers began to explore how the tenets of complexity can apply to social organizations, most notably in economics. Much of this work has taken place under the auspices of the Santa Fe Institute[14] founded by George Cowan and his colleagues in 1984.[15] Complexity theory "portrays the economy not as deterministic, predictable, and mechanistic, but as process dependent, organic, and always evolving" (Arthur, 1999, p. 107). Economies consist of multiple elements, adapting and reacting to the patterns created by those elements; evolving and unfolding over time. As Kauffman (1995) states, "economic systems link the selfish activities of more or less myopic agents" (p. 28). Kauffman takes this a bit further in his description of a democracy, in which people are organized into communities, each acting for its own benefit, working to seek compromise among conflicting interests. In a more ordered regime, poor compromises may be found

[13] The term 'butterfly effect' refers to the title of a paper Lorenz delivered to the American Association for the Advancement of Science (AAAS) in 1972, which was titled, "Predictability: Does the Flap of a Butterfly's Wings in Brazil set off a Tornado in Texas?" The example of such a small system as a butterfly being responsible for creating such a large and distant system as a tornado in Texas illustrates the impossibility of making predictions for complex systems; despite the fact that these are determined by underlying conditions, precisely what those conditions are can never be sufficiently articulated to allow long-range predictions.

[14] More information about the Santa Fe Institute can be found at http://www.santafe.edu/

[15] For a good narrative about the Santa Fe Institute and its history, see Waldrop (1992).

quickly; while in a chaotic one, no compromise is ever settled upon. It is at that edge between order and chaos, in a democratic system, where perhaps the better compromises can be found (Kauffman, 1995). But at this edge, the human agents, who are co-evolving with each other and the system, cannot determine the unfolding consequences of their actions; the very definition of a complex adaptive system.

Complexity and education

Many current bureaucratic practices and structures created to operate American schools were directly derived from the success of the business model of the 19th century. In the early 20th century, the focus was on efficiency in management. Therefore, school districts have Boards (of Directors), and regional and building administrators; while students are placed in age-batched classrooms with separate and weakly connected functions. Students are moved from place to place in the building in order to utilize teaching resources and the physical plant efficiently. Attendance is mandatory. Schools operate five days a week over nine months, with the day broken up into 50-55 minute blocks in clearly delineated subjects. Standardized tests determine promotion to the next grade level, with schooling and learning seen as linear and predictable processes, similar to that of the world of work one hundred years ago. This model is being questioned and modified in both the business world (e.g.,Wenger, 1998) and the educational world, as schools increasingly are being recognized as complex adaptive systems, with a constancy in structure, organization, and operation (Ginsberg, 1997).

A school is a dynamic system, involving the interaction of students, teachers, administrators, parents, etc., and it is governed by explicit and implicit rules of conduct, needs, order, and expectations. A thriving school (or classroom) fits the definition of a complex system in that it is: adaptive, emergent, holistic, non-linear, open, self-organizing, sensitive to initial conditions, and exists optimally at the edge of chaos. As Davis and Simmt (2006) state; "complexity science deals with self-organizing, self-maintaining, adaptive phenomena -- in brief, with systems that learn" (p. 5). Though complexity science has originated for the most part in the natural sciences, many of its concepts have been explored in the areas of cognition and learning; classroom environment; educational research; preservice teacher education; and professional development. For the purposes of this chapter, I will limit my discussion to the first three areas.

Cognition and Learning

Davis and Sumara (1997) state that, "cognition does not occur in individual minds or brains, but in the possibility for shared action" (p. 105). In this enactivist perspective, "the individual is understood to be part of – a subsystem to – a series of increasingly complex systems (such as a classroom, a school, a neighborhood..." (Davis & Sumara, 1997, p. 117).[16] It is not my intent here to explore whether learning is individual or social, or both, for that matter. However, teaching and learning occur in the context of interactions between individuals and collectives, and learners are themselves part of the context. An individual can be considered to be a complex adaptive system, but can also be treated as a fundamental unit in the classroom community, where it is interactive, yet autonomous (Davis & Sumara, 2000). The authors continue by declaring that "individual knowing, collective knowledge and cultural identity become three intertwining, self-similar levels of one phenomenon [the classroom community]...which can only be understood in relation to one another" (Davis & Sumara, 2000, p. 834).

[16] Enactivism is a theory explaining the co-emergence of learner and setting (Varela, Thompson, & Rosch, 1991). Enactivists explore how cognition and environment become simultaneously enacted through experiential learning. The first premise is that the systems represented by person and context are inseparable, and the second that change occurs from emerging systems affected by the intentional tinkering of one with the other.

The classroom collective, which can be seen as a collective learner, rather than a collection of learners, is the learning system that a teacher can most directly influence (Davis & Simmt, 2006). Classrooms and schools can be seen as emergent, cognitive entities, with cognition itself embodied in the classroom, or school, collective, rather than being limited to the separate individual mind or body (Laidlaw, 2004). However, this perspective, while illuminating, does not completely describe the classroom of today in the United States. Other structures exist as well. For example, school is a competitive meritocracy; with students assigned grades, teachers at times promoted on the basis of their students' test scores, and school funding dependent on those scores as well. These external pressures cannot be discounted.

For me, the classroom as collective learner idea relates well to the concepts of social constructivism, where the meaning attributed to individual learners is strongly mediated by the social environment. In addition, Davis and Simmt (2003) see complexity theory as a meta-discourse for use across both radical and social constructivism. Individual cognition can be understood by regarding "the learner as an autonomous agent working to fit with her or his context, as a component of a larger social order, as a complex collective of dynamic bodily subsystems, and so on" (Davis, Sumara, & Luce-Kapler, 2000, p. 73). The classroom community is an emergent and complex system, with the individual learner nested within that structure. The classroom is a collection of students, teacher, and, in this case, a researcher. How we interact together creates a complex adaptive system, with its own unique characteristics. As a researcher, I found that one component of a complex research environment cannot be separated out completely from the other components, or from the collective classroom entity. The entire system needs to be observed, examined, and reflected upon. In a complex research environment, one cannot answer definitive questions such as "does technology improve student learning?" Rather, one may, as I have, closely examine the practices that may emerge in the context of technology use in the classroom structure.

Complex classroom environment

The life of a classroom is synergistic. Aspects that are often examined independently in the Cartesian model of school, such as teacher training, curriculum selection, testing, grouping, etc., are actually part of a holistic learning system, which by definition must be studied as an interwoven whole. Any learning effects are highly interdependent outcomes of complex social and cognitive interactions (Brown, 1992). The sheer interrelatedness of the classroom can be intimidating, but with the addition of the classroom as a collective learner principle as mentioned above, contemplating how one teacher or researcher can begin to affect or study such an entity is daunting. Contemplating and operationalizing such concepts on the larger scale of a school district or state is something that is beyond most governing structures. Nonetheless, the concept of a classroom collective learner (or other group of learners) is one that is intriguing to explore.

What conditions must be present to allow emergence of a complex learning system in a classroom, or a 'collective learner,' as described above? Of course, the basic conditions of a complex system must be present, in that the learning community should be: adaptive, emergent, holistic, non-linear, open, self-organizing, sensitive to initial conditions, and often operating at the edge of chaos. Put another way, what conditions must be present for the emergence of co-activity in a community of learners that will "give rise to previously unrealized orders of organization" (Davis & Simmt, 2006)? For the following section, I draw heavily upon the work of Davis and Simmt (2003), as a framework. The necessary, but insufficient, conditions they list are:

- internal diversity,

- internal redundancy,
- specialization,
- decentralized control,
- enabling constraints, and
- neighbor interactions.

The variations among agents that make up a collective, and determine its range of possibility, are referred to as internal diversity. This diversity allows the system to respond flexibly, appropriately, and intelligently to changes in internal and external circumstances. In an internally diverse complex system, the elements of understanding necessary to make sense of a problem or idea are already present. The collective is responsible for finding a way to represent that understanding, but usually it will be the teacher who facilitates this process of negotiation among the various sources of diversity.

However, though internal diversity is needed, redundancy, or some degree of 'sameness' among agents, is also crucial. This allows agents to interact, and also allows agents to compensate for others' failings (Davis & Simmt, 2003). In a classroom collective, this means more than shared vocabularies, symbols, and resources; but also experiences, expectations, and purpose.

Redundancy allows for stability, while internal diversity contributes creativity. Both of these are related to the degree of specialization of the agents. For example, in this study this means that one would be attending to the types and the range of prior experiences, knowledge, dispositions, etc., that the students, teacher, and researcher bring to the learning environment. Minimum redundancy, or high specialization, would be valuable in fixed and settled conditions, but would be less than ideal in more volatile settings. Maximum redundancy, or low specialization, would be better in the face of sudden change. However, dramatically low levels of internal diversity discourage adaptation, or flexibility of response. This concept is closely related to that of a complex system existing on the edge of chaos, i.e., in the place between an area of high order and one without form.

The concept of decentralized control, or self-organization, is of interest. In a complex learning system, performing at its best, there is no controlling agent, but rather a "collective phenomenon of a shared insight" (Davis & Simmt, 2003, p. 153). It's really not a matter of a teacher-centered or a student-centered classroom. To be an effective teacher in a complex learning system, one does not maintain control, but strives to distribute control throughout the system; allowing for knowledge to be spread across all agents' actions.

Enabling constraints determine the boundaries of activity for a learning system, but not limits of possibility. Also referred to as liberating constraints (Davis, Sumara, & Luce-Kapler, 2000) or structures, they "maintain a delicate balance between sufficient organization to orient agents' actions and sufficient randomness to allow for flexible and varied response" (Davis & Simmt, 2003, p. 155). Again, this is related to the space at the edge of chaos.

The final condition delineated is that of the need for appropriate neighbor interaction. Neighbors in this context are not people, or the agents in a complex learning system, but rather "ideas, hunches, queries, and other manners of representation" (Davis & Simmt, 2006, p. 312). There must be some avenue for these ideas to be expressed so that other members can interact with them, and there must also be sufficient density to allow for ideas to play off one another. This is not necessarily provided through student grouping, but rather concepts and understandings must be able to interact within the structure of the community.

The Role of the Teacher in the Complex Classroom

How is a complex learning system created and nurtured? Does the very act of creation and active maintenance mean that it can no longer be considered as complex? How does a teacher fit into this complex environment? Is an effective teacher comparable to an artist; a jazz musician responding and improvising instinctively to critical points in the music as they arise (Iannone, 1995)? If such teaching is truly an art form, how does one teach a teacher to be such an artist?

What can a teacher do to create and maintain a complex learning system? The image which remains in the foreground for me is that of complexity existing on the edge of chaos; in that fertile region between order and stagnation on the one side, and formless lack of order on the other; a balance of creativity and stability. Most of Davis & Simmt's conditions relate to this image, especially that of enabling or liberating constraints. However, if one attempts to apply all of the conditions above, it quickly becomes apparent that the teacher cannot ensure all of these things will be in place at the beginning of the school year. For example, the teacher often has no control over which students will be placed in his/her classes. This means that internal diversity, redundancy, and appropriate specialization cannot be a given. While the students may not be highly diverse in terms of socioeconomic status, language, ethnicity, etc., each child will bring a diverse set of experiences to the classroom community. It is the teacher's task then to acknowledge and draw upon these diverse resources, along with her own as well. In this study, I also as the researcher brought my own array of diverse experiences to the classroom.

Flexibility in teaching and structure are promoted by many authors (e.g., Ginsberg, 1997; Iannone, 1995; Laidlaw, 2004; McAndrew, 1997), though in the current era of standardized tests and accountability, this can be more challenging. The idea is that if students (and the teacher) are given enough flexibility in intellectual and social organization, they will solve problems in their own way and in their own time. Emergent features of the complex classroom will then encourage self-organization. However, once again the outside pressures exerted upon the complex learning community must be acknowledged.

Again, I draw upon the work of Davis and Simmt (2003; 2006), specifically the conditions necessary for the emergence of a complex learning system in the classroom. In the beginning of the term, structures can be put in place that will encourage these conditions. Of course, as a complex system, small changes in initial conditions can yield large results at a later time. It is best to develop these structures at the beginning rather than to modify them later (Laidlaw, 2004), as once patterns are set in the classroom, the tendency is to continue with them.

Though a teacher does not necessarily choose his/her students, internal diversity of ideas can be nurtured in the classroom. To begin with, appropriate norms of engagement should be established. Most importantly, diverse contributions should be valued and encouraged, with less emphasis on getting to a single, correct answer to a problem or question. Students should be encouraged to build upon, and extend, the responses of others. Closely tied to diversity is redundancy. This work to build "common understandings among agents… to enable the emergence of collective understandings" (Davis & Simmt, 2003, p. 160) may include establishment of expectations for classroom interactions, appreciation of divergent contributions, and standards for acceptable explanations, among other norms. Both internal diversity and redundancy are closely tied to the concept of agent specialization. As mentioned previously, a high degree of specialization can be beneficial in a more stable classroom, with a lower degree being best in a more volatile classroom. Specialization can be promoted by the teacher, if so desired, by encouraging diverse explorations of concepts by students.

A truly complex system has decentralized control, with no governing structures or privileged members, and would be quite difficult to find in a public school system. However, in a social setting involving humans, one has to start somewhere! Therefore, the teacher, as mentioned above, initially works as a leader to set norms and expectations with the class. However, in a complex learning system, the learning that occurs can happen in a decentralized fashion. The teacher may set the question for discussion, but s/he does not lead discourse to a preordained destination. This does mean that the teacher must use care when selecting the question, so that it fits the goals s/he may have. In a complex environment, goals may be broad, general, and temporary, depending upon what unfolds in the classroom (Iannone, 1995). Specifically, students can be given varying amounts of freedom in the classroom so that they can spontaneously organize themselves and their knowledge (McAndrew, 1997).

Again, it is the norms, structures, and expectations that a teacher sets within a classroom community that enable the creation of an emergent, collective, environment where 'neighboring ideas' can interact. If diverse solutions are encouraged and valued; if common understandings of the work of the complex learning system are agreed upon; and authority is not centered upon the teacher, an interesting and vibrant balance at the edge of chaos can be maintained.

Complexity and education research

Complexity theory has a focus on evolving and changing systems, notions which are central to learning and teaching. This has resulted in an increasing number of publications exploring the application of complexity theory to the educational setting (Phelps & Hase, 2002). A website (http://www.complexityandeducation.ualberta.ca/) has been created in support of this work, along with a series of annual conferences; a new journal entitled

Complicity, and a SIG (http://www.udel.edu/aeracc/) at AERA. Authors have utilized complexity to explore (among others): the nature of learning (Jörg, 2000); student cognition and discourse (Bloom, 2001); and links to constructivism (Doolittle, 2001). Davis and Sumara (1997) apply complexity theory to their enactivist model of cognition in order to make recommendations for teacher education and research. It is primarily through their work (along with their colleagues) that I explore the issues of using complexity theory as an analytical frame in my research setting.

In my work, I examined specifically a technology-rich elementary science classroom. Rather than adopting a reductionist approach by attempting to analyze each component separately, I documented the features of the complex learning system as a whole, while actively searching for emergent behaviors at different levels of organization. In this approach, I was able to capture the productive interactions of teacher, students, technology, curriculum, and researcher as we worked together to construct understanding.

Chapter Four: Research as an Emergent Practice

The life of a classroom is synergistic. Aspects that are often examined independently and sequentially (for example, using a Cartesian model of researching school life where one might focus upon teacher training, curriculum selection, testing, student grouping, etc.) are actually part of a holistic learning system, which by definition should be studied as an interwoven whole. Any learning effects are highly interdependent outcomes of complex social and cognitive interactions (Brown, 1992). The sheer complexity of this interrelatedness of the classroom can be intimidating, but viewing the classroom in terms of a collective learner principle, as mentioned in the previous chapter, is intriguing.

As Sumara and Davis ask, "how does one trace the entangled involvements, the overlapping, contestatory, dissonant, discursive systems, resolutory practices, and normalizing discourse that circumscribe all complex systems" (Sumara & Davis, 1997, p. 304)? It is common for researchers in all fields, but especially in education, to look for simplicity, order, and authority in their research (Florio-Ruane, 2002), but complex phenomena cannot by their very nature be described or explained in such a way. Objective 'outside-in' research, in which the researcher objectively records and analyzes classroom events, will fail to capture the complex nature of the interactions in the collective classroom setting. Therefore, in order to shed light upon the complex learning community of the classroom, the researcher must become a member of the community, and employ the methodology of an in-depth case study.

In such a naturalistic inquiry of an emergent system, what will be learned depends on the interactions between the researcher and the research context. These interactions are not fully predictable, nor can the mutual effects be known until they are witnessed. Therefore, the research design must unfold, cascade, roll, and emerge (Lincoln & Guba, 1985). The complexity researcher will look for patterns of relationships that connect aspects of practice, rather than cause and effect explanations. In addition, in order to study a complex system, some complex research methods may be called for. As Reason and Goodwin (1999) relate, researchers may employ a mix of 'Apollonian' and 'Dionysian' methods. Apollonian methods are ordered, planned, rational, seeking answers through systematic inquiry; while Dionysian methods are passionate, spontaneous, and emerge in the moment. Research of complex systems then itself exists on the edge of chaos.

My role in the research classroom was that of a participant researcher in a case study. This term in itself is ambiguous, as participant research takes place in a variety of locations on the continuum between complete participation and complete observation. Here, in this more 'Apollonian' chapter, I will place participant observation in the context of qualitative, ethnographic, case study research; and explore my emergent role as a researcher in the complex environment of this Bayview Elementary classroom. In this chapter I will thoroughly describe the research context and participants; and also delineate the instruments and procedures used to collect and analyze data.

Participant Observation as a Way of Educational Research

In context

For the questions I wished to explore for this research project, I employed methods appropriate for a qualitative, ethnographic, case study. Qualitative research in education is about trying to understand what students and teachers do in the environments in which they work. It takes place in natural settings, in which the focus is upon participants' perceptions and experiences, and how events unfold in the regular context of the community. The researcher, as the primary instrument for data collection, gathers descriptive data within a flexible and emergent research framework (Bogdan & Biklen, 1992; Creswell, 2003; Denzin & Lincoln, 1994; Marshall & Rossman, 1999; Merriam, 1998). Qualitative researchers are intrigued by the complexity of social interactions as shown in daily life, and with the meaning that participants give to these interactions. The research itself is pragmatic, interpretive, and grounded in the lived experiences of people in a specific context. In order to gain these insights, the researcher typically spends a lot of time in the research setting in intense contact with the participants (Merriam, 1998). To be a qualitative educational researcher dictates flexibility, as there is no codified body of procedures that will guide the production of a perceptive, illuminating, or insightful study of the world of education. The research varies due to the researcher's interests, talents, and style. In addition, the researcher needs to remain aware of emerging configurations of the setting and flow of events over time, so that appropriate judgments and changes can be made accordingly.

Participant observation can be practiced as a form of case study (Jorgenson, 1989; Merriam, 1998), which is particularly effective when the researcher has, and/or desires, little control over events in the research setting (Cohen, Manion, & Morrison, 2000; Yin, 1994). The purpose for case study methodology is to retain the holistic and meaningful characteristics of real-life events and to understand the specific case under study, as well as to *describe* in depth how things were at a particular time and place, instead of trying to *explain* why things are the way they are (Stake, 1995). In this case study I provide a comprehensive, rich, detailed account of the Bayview classroom context for the reader.

Case study research usually entails long term placement of the researcher in the setting, but is bounded in time and/or space (Cohen, Manion, & Morrison, 2000; Creswell, 1998; Hitchcock & Hughes, 1995). My case for this research was limited in that I studied one classroom and its members over a defined period of five months. This timeframe, which began before the school year started, and ended soon after the winter holiday break, was appropriate in that I was in the classroom long enough to gather a large amount of data in order to gain insight for my research questions. It did not require me to withdraw completely from other portions of my life, and also allowed the classroom teacher a break from research for the last half of the year. This case was also limited to some extent by the focus of the research questions, namely the use of *technology* in the teaching and learning of *science*. Though class members worked in other content areas while I was present, my concentrated efforts were devoted to science. In addition, many different types of curriculum materials were used in science instruction, but I focused primarily on those involving technology. There was a boundary between the focus of the research and its context, and other areas which were not studied. For instance, I surveyed class students about their familiarity with computers in order to gain insight into their readiness to utilize technology in the classroom. This survey gathered data which included computer use at home, but I did not visit students' homes in order to study that area further.

Case study selection

Can this case study be considered as representative of some larger population or practice? Case studies can be seen as contributing to a larger body of knowledge that will then allow comparisons to be made. The logic of a case study differs from that of survey research's emphasis on gathering data from a large cross section of a population in order to make generalizations, or the focus of experiments on demonstrating causation by control and comparison of variables (Jorgenson, 1989). Some researchers may choose to study a case they define as 'typical.' I do not claim my case study as typical of all elementary classrooms, and would be hard-pressed to define a truly typical elementary classroom. However, I can describe in some detail the context of this particular classroom, and describe how it fits into the larger scheme of things.

Case study research often employs methods of ethnography, as did I in this project. As traditionally defined, ethnography involves a long period of intimate study and residence in a well-defined community employing a wide range of observational techniques, including prolonged face to face contact with members of local groups, direct participation in some of the group's activities, and an emphasis on intensive work with informants along with some use of documentary or survey data (Conklin, 1968). As a participant researcher in the Bayview classroom over five months, I practiced these techniques.

Ethnography has its roots in the field of anthropology, with researchers such as Franz Boas, Bronislaw Malinowski, Margaret Mead, and A.R. Radlciffe-Brown, and their work with comparative cultures. These researchers typically engaged in long-term immersion fieldwork with cultural groups such as the Kwakiutl Indians from Northern Vancouver Island and the adjacent mainland of British Columbia, Canada (Boas), and the South Pacific islanders of Samoa and New Guinea (Mead). Ethnography is now practiced by researchers in a variety of fields, including anthropology, education, sociology, and others. There is some debate in the social sciences as to what can be defined as an 'official' ethnography. Wolcott (2002) tackles this issue in a chapter entitled "Ethnography? Or Educational Travel Writing?" in which he argues that there is a difference between *borrowing* ethnographic techniques in data gathering and *doing* ethnography as a practice or method (emphasis added). While citing the traditional components of ethnography, e.g., holistic, first-hand, descriptive, conducted in natural settings, etc., Wolcott (2002) defines "the presence or absence of a notion of culture as the ultimate criterion for judging ethnographies" (p. 41). Culture here is used in its traditional sense, but also may include any equivalent concept or subset, such as social structure, worldview, political economy, or community of practice (as defined by Jean Lave). It ultimately is the cultural approach of an ethnographer that makes for a true ethnography in the classic sense. This is echoed by Merriam (1998), who states it is quite acceptable to use ethnographic *methods* without necessarily producing an *ethnography*.

Specifics of Participant Research

Participant research is perhaps the most intuitive type of research employed in the social sciences. From the moment we're born, we observe the world and attempt to participate in it. Participant observation as a data gathering strategy is so familiar, that some would argue that there are no pre-set formal steps to its successful performance (Jorgenson, 1989; Laurier, 2003). Also, the fact that participant observers often have very little control over the research environment contributes to its informal nature (DeWalt & DeWalt, 2002). The steps that are taken depend on the nature of the research itself, based on a process of continuing negotiation between the researcher and the researched. Together, the attributes and qualities of the fieldworker interact with those of the setting and its members to shape an *emergent* role for the participant observer (Horowitz, 1986). In my dissertation research, the project itself was emergent, with I as researcher having a general idea of the topic to be studied, but largely dependant on the information collected in the field to define and focus the problem to be studied (Jorgenson, 1989).

The meaning attached to participant observation and how it fits in the context of other methods such as ethnography varies between researchers. Spradley (1980) sees participant observation as the general approach to fieldwork in ethnographic research, and one which anyone can do, regardless of training or coursework. The researcher must work to become explicitly aware of a broad spectrum of information that is usually blocked out of conscious awareness in order to avoid overload, and be reflective about the process. DeWalt and

DeWalt (2002) are considerably narrower, and define participant observation as "a way to collect data in naturalistic settings by ethnographers who observe and/or take part in the common and uncommon activities of the people being studied" (p. 2), separate from interviewing, observation, and analysis of texts. It is only the information "gained from participating and observing through explicit recording and analysis" (p. 2) that can be considered participant observation. Wolcott (1995) writes that participant observation is not really a method at all, but rather a strategy that facilitates data collection -- both quantitative and qualitative-- in the field. Jorgenson (1989) continues in this vein by listing a variety of methods which can be included within the larger method of participant observation. These methods include direct observation, the researcher's immediate experience, documents, artifacts, informants, interviews, questionnaires, journals and logs, written or tape-recorded materials, and audio or video records. The consensus appears to follow along the more flexible interpretation, with participant observation defined as employing multiple and overlapping data collection strategies while being fully engaged in a setting, observing, and talking with participants (Patton, 2002).

As with any data gathering strategy, there are advantages and disadvantages to participant observation. On the positive side, it covers real events in real time, addresses the context of events, and provides insight into interpersonal behavior and motives. On the negative side, participant observation is time consuming, is often selective in its coverage, may have an influence on how events proceed, can be expensive due to the time investment of the researcher, and can be biased due to the researcher's conscious or unconscious manipulation of events (Yin, 1994).

One of the fundamental issues in participant observation is at what level(s) a researcher participates, and/or observes. As the researcher is the primary instrument of data collection, the role of that person has great bearing on an investigation. Over the years, many have written about this issue; often using the image of a continuum of involvement, as seen in Figure 4-1.

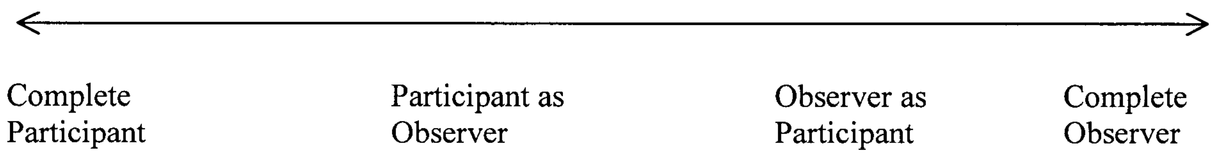

Figure 4-1. The Continuum of Participant Research (Gold, 1958)

Gold (1958) defines these discrete roles in naturalistic settings as follows:

- Complete participant: becomes a member of the group under study, and is often covert. The covert role can be stressful to maintain, and the researcher may become too self-conscious to continue. Another hazard is 'going native,' or forgetting role as researcher.
- Participant as observer: is overt, but is still a member of the group. It is important to maintain some elements of the 'stranger' to guard against too much intimacy with group members.
- Observer as participant: Observation is more formal here, and may happen only over one visit. The danger here is the superficial nature of the visit, which may result in misunderstood information.
- Complete observer: Usually those observed don't even know they are being observed. It can be difficult for the researcher to understand what is happening, due to outsider status. Sometimes a researcher may act in this role when searching for a venue for further research.

Other researchers subscribe to the continuum view of participant observation, but use different terms for the roles. For example, Spradley (1980) uses the terms complete participant, active participant, moderate participant and passive participant; while others (Adler & Adler, 1987) use full membership, active membership, and peripheral membership.

Gold (1958) was perhaps more rigid in his role assignments, as he wrote that the researcher needed to choose **one** role which would work best for the research goals and then stick with it throughout the project. A contrasting view is provided by Glesne (1999), who sees the roles as less divided, allowing the researcher to be at different points on the continuum at different times in the research. There are advantages and disadvantages to each role, as "the more you function as a member of the everyday world of the researched, the more you risk losing the eye of the uninvolved outsider; yet, the more you participate, the greater your opportunity to learn" (Glesne, 1999, p. 44).

Regardless of where the researcher wishes to be on the continuum, there are certain skills which are beneficial. The participant observer should: a) be able to ask good questions, and interpret the answers; b) be a good listener, and not be limited by personal ideologies or preconceptions; c) have a firm grip of the issues being studied; and d) be unbiased, sensitive, and responsive to contradictory evidence (Yin, 1994). In effective observation, the researcher explicitly and self-consciously attends to the events and people in the context they are studying, with all senses. It is also important to practice self-observation of how one experiences the setting as a participant (DeWalt & DeWalt, 2002). In the Bayview classroom, I was careful to take notice of how I interacted with Belinda, the students, and the technology.

Research Context of this Study

The Setting

Bayview Elementary, in a coastal community of a Pacific Northwest state, is a school of approximately 250 students in grades kindergarten through five, with approximately 25 faculty and staff. The population is predominantly white and of medium socioeconomic status (25% of students receive free or reduced lunch). Students at Bayview have consistently scored higher than the state average on standardized tests over the last ten years. Bayview, a three-storey brick building built in 1914, and the surrounding neighborhood have an established history, with many current students being descendants of Bayview alumni. Though an older building with some seismic instabilities, it is a well-loved and maintained school, embedded in a highly involved community. The parent community is very involved in the life of the school, with many volunteers to be found in classrooms and the media center. Members of the school community are fortunate also in that the building has a commanding view of a coastal bay and offshore islands.

I collected data as a participant researcher in the school over a period of approximately five months, from August 2002 through January of 2003. The third-floor classroom in which I conducted my research was a 4th/5th grade multiage environment. For many years, Bayview intentionally maintained multiage classrooms. In 2001, that practice ended in the face of parent opposition. However, in 2002/2003 the student enrollment numbers were such that a multiage arrangement was necessary in some classrooms. The classroom teacher, Belinda Knudson, was always quite comfortable in the multiage setting, and was satisfied with this arrangement. Six of the 24 students were 4th graders who were chosen on the basis of their anticipated ability to mesh with the 5th graders academically and socially. The class was treated as a whole, with the only exception being the infrequent departure of the 4^{th} graders to study state history in another 4^{th} grade classroom. The class was evenly divided between male and female students.

How this Case was Selected

I chose this classroom and teacher for my research for three reasons. First, I was familiar with Bayview personally as my son was a student there for five years. Second, I was familiar with Belinda Knudson professionally as I had worked at Bayview in my capacity as an intern supervisor from the local regional university. When I began to look for a place to do my science education research, I immediately thought of Belinda, as she was the only intermediate teacher at Bayview who consistently taught science. Third, Belinda Knudson was a district-funded participant in the local Gates Grant, which meant that she had eight high-speed Internet computers in her classroom. However, as she was a district-funded participant, she received only equipment and very little training. This frustrated Belinda, who shared with me that she was comfortable with the technology, but that she felt she and her students were not benefiting as much as they could from it. My initial research goals were to describe the emerging practices of an elementary teacher and students as they interacted with technology tools in the context of science. So, as I believed that I could provide some insight and experience with science and technology for Belinda, and her classroom would be a good match for my research goals, we decided to embark on this project together.

The building principal and school district officials were very supportive of my research project, as I had an established professional and personal reputation in the area. As I began my work in the classroom, the staff at Bayview accepted me easily into their group, with some faculty very interested in the project. In addition, I was customarily invited to after-work social gatherings by the teachers. I also served as a member of the school

Technology Committee, along with Belinda, during my time at Bayview. Belinda and I usually ate lunch in the staff room, and I brought treats per the regular schedule.

During the period of active data collection, I was in the classroom for a minimum of two successive full days per week.[17] That did not mean that students were engaged in learning only science, specifically astronomy, the entire time I was in the classroom. Belinda strongly believed in integrating across subject areas, so the focus was on science content and technology those days, but students also engaged in language arts, math, art, social studies, etc., that related to the topic of astronomy.

The science area of study during my time in the Bayview classroom was astronomy, specifically the solar system and its exploration; part of the district-mandated 5th grade curriculum. Originally, the topic was to be water, a 4th grade topic, but during the latter part of the summer, the composition of the mixed 4th/5th grade class shifted more towards 5th grade, which suggested the curriculum change.

Research Ethics

In the spring preceding my research, I requested and obtained approval for the project from the UBC Behavioural Research Ethics Board. I submitted an abbreviated research proposal to the Bayview school district, met with the assistant superintendent, and also with the building principal. In my proposal, I stated that any information which could identify participants resulting from this research study would be kept strictly confidential, and that participants would not be identified by name in any reports of the completed study. The district approved my proposal, as did the building principal. When that principal left the building over the summer, I obtained the approval of the new principal in August. During the summer I also obtained written consent from Belinda Knudson.

[17] For the week before, and the first two weeks of school, I was in the classroom all day, every day.

At the beginning of the school year, I sent an informed consent form home with each student in order to obtain student and parent approval for my research. One or two parents contacted me with questions, but all students and parents agreed to the project and signed the forms. Both Belinda and the students originally stated that they would not object to the use of their names, but I was more comfortable with pseudonyms and proceeded in that manner from consent onward. All consent forms stated that I could use still and video images of participants in my research and its presentation, so long as they were not identified by name. During the project, I was careful to keep my notes secure, and also respected all district rules regarding student privacy.

Research Participants

In 2002, Belinda Knudson began her ninth year of teaching. She completed a Masters Degree in educational technology in 1999, at a university in a nearby city. Belinda was an active participant in the school, as were all teachers in such a small school. She was on the SITE Council and a member of the Technology Committee, placing her in a leadership role in that area. There were two other teachers of students in the same age group in the building. She also maintained an open classroom, frequently welcoming colleagues and interns into her classroom. Belinda, a single Caucasian mother of one, has considered pursuing an administrative credential, but not until her young son becomes more independent.

During the research period, an intern, Melissa Horner, was present at times. However, as she was only in the classroom a few hours per week, I did not include her as a participant in the research framework.

At the beginning of the year, there were 24 students in the classroom, twelve boys and twelve girls. That total oscillated very little during the year, with only one female student leaving, and one male arriving. All students spoke English as a native language, with three of Hispanic origin, and the remainder Caucasian. One student received supplemental special education assistance for a learning disability for an hour each day.

My role as a Participant Researcher in the Bayview Classroom

Role Definition

As I entered into the research environment at Bayview Elementary, I worked to define what my role would be as a participant researcher. I was guided by this statement from Bogdan and Biklen (1992), "(h)ow you participate depends on who you are, your values, and your personality," but one should always think, "my primary purpose in being here is to collect data. How does what I am doing relate to that goal?" (p. 90). The continuum from complete participant to complete observer is a long one, with many possible positions along the way, and the data that I would gather would vary depending on the role I chose. Atkinson and Hammersley (1994) discuss participant observation and the ambivalence of distance and familiarity, while Spradley (1980) reminds us that the more you know about a situation as an ordinary participant, the more difficult it is to study it as an ethnographer. The benefits of playing both roles are high, however. Firsthand involvement in the study would allow me to hear, see, and begin to experience reality as classroom participants do, and to learn directly from my own experience (Marshall & Rossman, 1999). However, as an outsider, I would have an overview of the scene, and could note major and distinctive features, relationships, patterns, processes and events, usually through a more objective lens (Jorgenson, 1989).

The fact that I was already known to the Bayview School and larger school district community served me well as I set up my research project. My past association with Belinda not only helped us to feel comfortable together, but also had given Belinda an idea as to who

I was professionally in the context of science education. I also knew Belinda as a teacher who made time to study science with her students, and who was comfortable with trying new things. As we planned how my research project would fit with her classroom teaching, we discussed what my role would be in her class. I would be spending five months in the classroom, so obviously, I could not remain covert as there would be nothing to explain my presence (K. D. Bailey, 1987). The question was of degree of participation. If I acted in a familiar teacher role, students would be likely to do as they normally would around any other teacher. I would be present in the classroom only two to three days per week, so complete team teaching was never considered. However, neither of us was comfortable with the idea of me sitting in the back of the classroom, taking notes and observing only.

I believed I would need to guard against participating too much and stepping out as an observer too little. In my past role as a student teacher supervisor, I had always worked hard to remain an outside observer of the classroom as much as possible, especially when I first started out. However, I had soon found it difficult to remain completely external. In fact, I learned that when evaluating a student teacher, it was often beneficial to move among the students as they worked, asking them about what they were learning. This gave me more data to gauge the success of a lesson. Of course I never consciously took on the role of the teacher, but many students perceived me in that way. Would I want students in Belinda's classroom to engage with me as a teacher, an outsider, or somewhere in between? The children would define me in a particular way, dependent on my role in the classroom (Bogdan & Biklen, 1992).

Belinda's teaching style was not traditional, in that she would rarely stand in the front of the room, deliver a lesson, and then expect students to work independently. Rather, she would start the class off with a few ideas, set them to work, and then move among them as they worked individually or in groups. I began to refer to this as the 'start the top spinning' method of teaching. In order to observe the students and Belinda as they worked together, I would need to move around the classroom and be a participant myself at some level.

Ultimately, Belinda and I wanted the students to derive the most benefit from this research as possible. Therefore, I would be sharing my numerous astronomy teaching resources. Though Belinda was comfortable with the subject, astronomy is one of my favorite areas, and one that I enjoy teaching. This sharing of information would most likely cause me to encourage work in certain areas, intentionally or not. It would be a natural progression for us to teach together using these materials when I was present in the classroom.

The negotiation of the relationship between a university researcher and a classroom teacher is discussed in the literature. For example, Goodlad (1988) talks about symbiotic partnerships in which each partner has his/her own interests, but work together to achieve their goals. However, the relationships between teachers and researchers are riddled with a host of power differentials that affect multiple aspects of teaching and research dynamics. The natural social roles, identities, and discourses of teachers and researchers interact, enable, and constrain their work together (de la Luna & Kamberelis, 1997).

Our collaboration between teacher and researcher would be self-organizing. Belinda and I had to establish our roles, but they would continually fluctuate throughout the project. This was not a difficult or painful process as we had the utmost respect for each other from the very beginning, and we maintained a good level of communication. Over the summer before the project began, we had numerous discussions, both structured interviews and casual talks, about how we would proceed. We sketched out what topics would be explored, along with pedagogical possibilities, but at that point we did not map out exactly what would happen each day throughout the fall. Both of us were comfortable with letting events unfold and emerge in the classroom, with the students and their interests guiding us to a great extent.

Evolution of my Role in the Classroom

My role was not covert in any way, but open from the very beginning, with written permission for research participation obtained from children, parents, building principal, and school district. From the beginning, I was introduced to the students as 'Ms. Popejoy,' a science educator and teacher from my local university, who was working on a research project to get a doctorate in the field. I told the students that I was going to spend some time in the classroom learning about how they and Ms. Knudson used technology when learning about science for the most part, but also in other curriculum areas. Belinda and I let the children know that while I would be interacting with them in various ways as they went through their day, I was not going to be their teacher. My identity was established as someone who was knowledgeable about the topic of astronomy, and also as a teacher in a different context. How Belinda and her students interacted with me would also determine my role as a participant (Abell, 2000), and that could (and did) change over time. I was fortunate in my smooth entry into the research environment. Many hundreds of pages in the participant research literature are devoted to entry of the researcher into the community, how to meet informants, and how to be accepted (Collins, 2002; DeWalt & DeWalt, 2002; Glesne, 1999; Jorgenson, 1989; Yin, 1994). However, due to my familiarity and comfort with Bayview, Belinda, and the students, I did not need to rely upon this work.

The research project was deliberately planned to start at the beginning of the school year, which allowed both Belinda and I to start fresh with all of the students. As a researcher, this was ideal as no real classroom community was established which I would have to 'infiltrate.' Rather, we would all get to know each other together. To facilitate this, Belinda and I spent the week before school together, setting up the classroom, exploring curriculum materials, updating technology tools, and planning instruction. I then spent every day of the first two weeks in the classroom. During this time, I made a concerted effort to spend time observing the classroom, taking notes, making diagrams, taking photographs, videotaping, etc., but I also got to know the students as I sat with table groups, circulated through the classroom, and worked recess duty with Belinda. My role as a researcher was clarified as students asked me about the project and I asked students to complete a questionnaire about their computer use. However, I at times took on the role of a teacher when students asked me questions, or for help with computer issues.

Abell (2000), a university professor, discusses the tensions that she felt within herself as she worked as a researcher and teaching partner in an elementary science classroom. Her role was more explicitly defined as a peer teacher, and she acted more as a teacher than I did. However, throughout the project, I was aware of the pull of teaching over that of the observer. I didn't want Belinda and her students to feel 'studied' as I sat in the back of the classroom busily writing in my notebooks. I also wanted students to feel at ease in my presence so that they would act naturally and not as they might think I wished them to as a researcher. Ultimately, I enjoyed interacting with the students, and sometimes had to 'force' myself to step back in order to try to view the environment as an outside observer.

Abell (2000) also discusses the tensions between herself as a university researcher, and the classroom teacher. Abell wished to be a peer collaborator, but the teacher continued to see her as the professor/authority. This position allowed Abell to model lessons and provide resources, but also resulted in discomfort for the teacher. I chose not to be a complete collaborator and co-teacher with Belinda in the classroom, but rather to provide materials and assistance as she asked for them. Belinda was always in control of the classroom and its curriculum, with me in a support role. As Belinda planned her instruction, I worked with her and gave input as she desired, but I did not consciously lead her in any particular direction. When she was involved in direct instruction with the students, I never stepped in or added comments unless invited to do so.

Over time however, my role evolved as we worked together. At times, I would read aloud to the class after lunch so that Belinda could prepare a lesson. Once, after Belinda had taught a traditional lunar phase lesson with a light bulb and Styrofoam™ balls with me observing, she asked me to work with the students and materials again as a post-assessment, so that she could observe how the students learned the concepts. One morning, due to a mix-up with a substitute teacher, I 'took control' of the class for about 90 minutes until the substitute arrived. In addition, at times we divided the class in half and taught the same lesson so that materials could be used more efficiently. Usually, these episodes of my 'formal teaching' were planned for deliberately, but we also naturally adjusted to events as they unfolded. This was made possible through our mutual respect for each other and our expertise. I truly enjoyed working with these children who were so fascinated with space and space exploration, especially as I am quite passionate about astronomy myself. I had to continually remind myself to step back and record our experiences in some manner.

I ran into the most difficulty remaining only an observer when students were working on projects on the computers. The classroom contained only eight computers, but next door in the library were four more. Students often overflowed into the library to work. As they worked, Belinda and I circulated. I always carried my notebook and made observations, but I also interacted with students as they ran into issues, had questions, or made interesting discoveries. It was at these times that I acted in a role most similar to Belinda's as teacher.

However, neither Belinda nor I wished for us to deny our expertise, rather we wished to share it for the benefit of the students.

How my Role aided Exploration of the Research Questions

My research questions for this thesis explored the practices of both the students and the teacher as they worked with science and technology. Acting as a teacher in ways similar to Belinda allowed me to experience what she did in the classroom even more. Not only did I observe her interacting with her students, I did so as well, allowing us to have a shared experience of teaching for continuing and later reflection. As we worked together regularly in the classroom and after school, I was able to discuss students and their work from my own experience with them, rather than merely listening as Belinda described it. My immersion in the classroom facilitated the 'thick descriptions' which lend themselves to reliable explanations and interpretations of events rather than relying on my own inferences (Cohen, Manion, & Morrison, 2000). I was engaged in the very activities I set out to understand. After all, "the best participant observation is generally done by those who have been involved in and tried to do and/or be a part of the things they are observing" (Laurier, 2003).

I remained on guard against letting participation dominate my time in the classroom (Bogdan & Biklen, 1992), and consciously took time each day to write observations of the events in the classroom. However, I found, as most researchers do, that it was difficult to find enough time to write thorough notes. I continued to negotiate positions on the participant-observer continuum which seemed appropriate for the various circumstances I encountered in the research environment. I worked to balance the costs and benefits of participation and observation over time as well, as I became more comfortable in the classroom.

I worked to stay 'out of the limelight' in the classroom (Glesne, 1999), and to defer to Belinda's position as 'the classroom teacher.' We were fortunate in that our styles and philosophies of teaching meshed quite well, in that we believed that it was far better to explore fewer topic areas deeply, rather than to visit many in a superficial way. Both of us enjoyed an easy familiarity with the students, and especially derived pleasure from their excitement about astronomy and space exploration topics.

Our communication was strong and regular, with both of us making the effort to find the needed time. In addition to our dialogue as we worked together in the classroom, we met after school at least once a week in order to reflect and plan. We also talked by telephone every Sunday evening, which allowed us to continue to negotiate our roles with each other and in the classroom. These times for planning and reflection were as, if not more, valuable than those we spent in the classroom. Belinda led the way in these discussions as much as possible, and I worked to follow her lead, doing my best to avoid nudging her thought processes in particular directions. At all times, I made it clear to Belinda that I was not evaluating what she and her students were doing in the classroom, but rather observing events as they occurred.

Our working together closely helped to bond the two of us as we shared the joys and frustrations of teaching. This encouraged Belinda to be frank with me as we communicated, both informally, and formally through the semi-structured interviews I recorded with her. We discussed learning, technology, change in practice, classroom structures, and science (all topics related to my research questions) quite easily. Belinda often commented on how much she enjoyed having another educator in the room to share the work that she usually did alone, but also one with different ideas, perspectives, and materials to offer. My immersion as a participant in the complex learning environment of the Bayview classroom allowed for a fuller appreciation of practices, events, and shared work of the community.

Data Collection

In order to collect data as a participant researcher, I employed a variety of techniques, loosely based upon suggestions from Glesne (1999). I observed, experienced, and recorded the classroom setting in detail, using words, sketches, and images. I established relationships with all research participants, including Belinda and the students, and worked to maintain a professional demeanor in the classroom. I noted participant behavior and classroom events, and watched for patterns and similarities.

Data gathered for a qualitative, ethnographic case study can include observation notes, audio and video recordings of events and everyday life, participant interviews, and physical artifacts such as student work and curriculum materials (Creswell, 1998). Relying on multiple sources of data allows for triangulation as needed to draw conclusions (Yin, 1994). I gathered all of these types of data, and in addition administered a short, written technology access survey to students.

Observation

As a participant researcher, I gathered data through a variety of ways, the primary one being observation field notes and reflections logged in a series of spiral notebooks with numbered pages. My notebooks were a place for descriptions of Belinda and the students, the classroom, lessons, activities, planning sessions, and conversations with participants; and also for ideas, reflections, hunches, reminders, and notes about emerging patterns. These notebooks were organized chronologically for ease of use and review. My notes were private, though sometimes a student would ask me what I was writing and I would show them what I happened to be doing at the moment (if it was not sensitive). Like many researchers, I found it difficult to remember to write everything down as it occurred, so in the evenings I would spend time writing about events and reflections from each day.

Digital video and still images

At the beginning of the project, I placed my personal digital still camera in the classroom so that Belinda and I could photograph the students as they interacted with technology on a regular basis. These pictures were downloaded to my laptop computer and used as another source of data at the analysis stage. In addition, I periodically used a digital videocamera in the classroom on occasions when video would be a richer source of data. I used the videocamera to document student presentations, but also to record student interactions with each other and with technology and curriculum materials as they worked. These videos were also downloaded to my laptop to aid in data analysis.

Why did I decide to include digital photos and videos in this project? Both were used as tools to record things which happened while I was away, and to help my recall of events in the classroom for which I was present. In addition, students often enjoy being photographed or videotaped as they present a project or are interviewed. However, I also see these digital images as a way of capturing the culture of the classroom, in addition to my extensive field notes. Data from video especially, can "enable a finely grained description that concentrates on minute details" (Goldman-Segall, 1998, p. 16) that can escape the attention of the researcher in the community. Data captured via photos or videos are really not more objective than written observations in that I, as the participant recorder, made the decision about what to film, where to place the camera, etc. It was my relationship with the Bayview classroom culture that was captured via video, just as it was through my notes (Goldman-Segall, 1998). I believe that visual representations of classroom activities, which can easily be shared with others, are an important component of my quest for a 'thick' level of description in this research.

Interviews

Observing a teacher or student provides access to their behavior. Interviewing allows us to put behavior in context and provides access to understanding their actions. If the researcher's goal is to understand the meaning people involved in education make of their experience, then interviewing is a productive area of inquiry (Seidman, 1998).

In order to explore Belinda's thoughts about using technology in her science instruction, I conducted five monthly semi-structured interviews with her. These interviews took place in the classroom after school, and were audiotaped and transcribed. We were often interrupted, but it was best for both of us to be in the research context, where we could reference various materials as needed. Appendix A contains a list of guiding teacher interview questions. Our interviews became less structured as the term progressed and we addressed emergent events in the classroom. Also, we conducted an extensive follow-up interview in February of 2003 in the more peaceful environment of my living room at home.

I also conducted semi-structured interviews with each student toward the end of the research period. These individual interviews took place in the school library, and were audiotaped and transcribed. In Appendix B I provide a list of guiding student interview questions. My intent in doing these interviews was to help students to describe to me how they perceived their interactions with technology in their science learning experiences. Most students were quite forthcoming in their interaction with me, while some were quite shy and abbreviated in their responses.

Physical Artifacts

During the second week of school (September 2002), I administered a short, written Student Pre-Survey of Computer Access and Comfort Level I had constructed to the students (see Appendix C). I did this so that I could ascertain something about their comfort level, access to, and variety of uses for computer technology. I also administered a post-survey of my own design in January 2003, at the end of the research period (see Appendix D).

In addition, I collected student drawings, worksheets, notes, pre- and post-assessments, and end-products of projects. Some of these items were on paper, but most projects were electronic, i.e. PowerPoint™, files. I also gathered district and school items, such as the District Technology Plan and Technology Assessment data, and the Bayview School Strategic Plan.

Data Analysis

Sumara & Davis (1997) write: "...teaching and research, like all cultural forms, are complex phenomena which resist simplistic reductions or interpretations" (p. 301). I found this to be the case with my data as I searched for emerging patterns. However, I also believe that a researcher must begin data analysis in an organized fashion of some kind. Therefore, here I explore some of the more traditional ways that I began to analyze the classroom data.

The goal of all data analysis, regardless of type, is the synthesis of large quantities of data into understandable information from which inferences and conclusions may be derived. Traditionally, a qualitative researcher employs an inductive approach to the analysis of the large amount of descriptive data that emerge in an ethnographic case study. Abstractions are built as the particulars that have been gathered are grouped together into patterns of understanding, with a focus on the meaning and nuances of the multiple realities as experienced by participants (Bogdan & Biklen, 1992; Marshall & Rossman, 1999). The researcher seeks believability, based on coherence, insight, instrument utility, and trustworthiness through a process of verification of observation (Creswell, 2003).

This is an iterative process of reviewing, summarizing, cross-checking, looking for patterns and themes, and drawing conclusions (DeWalt & DeWalt, 2002). While one part of analysis is the logical and methodical building of descriptions and arguments through reviewing and organizing materials into categories and themes, the other is the search for *emergent themes* and principles, which is often intuitive. Though I did not follow precisely the steps recommended in the grounded theory approach (Glaser & Strauss, 1967), I employed some of the techniques as I grounded myself in the data and formed hypotheses and theories. These techniques included constant comparison, convergence, and triangulation of data from a variety of sources, and the development of open codes as they emerged from the data. I also used member checking as I asked Belinda to review transcripts of our interviews.

Analysis while in the Classroom

Data analysis was truly ongoing from the beginning of my time in the classroom. Writing and reviewing observation field notes throughout my research time caused me to ask new questions, and look for continuing patterns. Throughout this process, I viewed the classroom as a holistic, complex, and emergent entity, and explored the dynamic pattern of relationships which connected aspects of classroom practice, rather than searching for cause and effect relationships (Reason & Goodwin, 1999). As I have discussed elsewhere, I had to learn to trust the emergent nature of the research; to let it unfold as I observed and took part in the classroom.

Belinda and I also examined and analyzed student work (physical artifacts), throughout the fall. We did this primarily to assess how students were working with the materials, but also to determine where we wished to go next. Again, this process was self-organizing. We had an idea of what we wanted to do at the beginning, but analysis of data caused us to go in directions we may not have expected. During my research in the classroom, I did not have the time to analyze photographs and video in depth, though I did review those that were taken while I was out of the classroom in order to see some of what I had missed. I did spend some time looking over the technology surveys I had given the students in order to determine their background. I also became familiar with the District Technology Plan and the Bayview Strategic Plan.

Analysis after Leaving the Classroom

Here, I employed a recursive strategy of sorting, shifting, comparing, constructing, deconstructing, and reconstructing all sources of data from the Bayview classroom. These included:

- Over ten hours of digital video footage
- Over 100 digital still images
- Ten hours of interviews with Belinda (transcribed)
- Ten hours of interviews with students (transcribed)
- 400 pages of researcher notes
- Student pre- and post- technology surveys
- Pre- and post-assessments in science from the children
- Student artifacts such as PowerPoint™ files, planet travel brochures, Mars colonization plans, and various assessments

I also revisited the literature for continuing insight. Initially, I read through all of my observation notes, interview transcripts, student work and technology surveys, school and district documents, and electronic communications between Belinda and me. I also tabulated the results from the student surveys. Then, I reviewed all photographs and video and downloaded them to my computer, organizing them into chronological files. As I did this, *I looked for emergent themes and connections,* making note of them on Post-It™ notes on the documents themselves, and in a separate spiral notebook for the visual representations. As a relatively linear person, I found it best to sort all of my data chronologically, regardless of source or format. A rudimentary system of coding of conceptual categories emerged through this process. Rather than developing an extensive and elaborate list of codes, I was guided by the advice of Creswell (1998), who suggested beginning with a list of only five or six codes, then expanding the list with additional codes and sub-codes in later stages of analysis. My initial codes were: teacher practice, student practice, technology interactions, student-to-student relations, teacher-student relations, and science curriculum items. However, I later sifted the data again, noting specifically instances of the characteristics of complexity (e.g., self-organization, internal diversity and redundancy, enabling constraints, etc.). It was this second stage of coding that finally allowed me to organize my data into emergent themes.

From these data, I began to outline a thorough description of the case and its setting; again working chronologically. As I did this, I analyzed all of my data forms to determine pathways for the evolution of the case. Stake (1995) suggests four forms of data interpretation and analysis for case studies. First, in categorical aggregation, one looks for a collection of occurrences or instances from the data that may represent a specific idea, category or theme (coding). Secondly, in direct interpretation, one looks at a single instance only from the data, not multiples, in order to derive meaning. Thirdly, one looks for patterns and correspondences. Lastly, the researcher develops naturalistic generalizations from the analysis of data. I found that I was doing all of these things, and more (though not in this particular order), as I waded through a tremendous amount of data.[18]

As a researcher, my initial instinct was to "seek simplicity, authority, and order" (Florio-Ruane, 2002, p. 205) in my research, i.e., cause and effect relationships, rather then to allow themes to emerge as I immersed myself in the data. Over time, I realized that my goal was a holistic interpretation of the data, in which I described the dynamic pattern of relationships which connected aspects of practice in the Bayview classroom. I needed to move beyond my customary Apollonian framework (Reason & Goodwin, 1999) of ordered, planned and rational models; and explore the Dionysian, spontaneous, emerging themes that arose from the data. Truly, this emergent, complex case study required emergent, complex methods of research and analysis. In the next several chapters, as I begin my analysis of the case, I provide a rich thick description of the Bayview classroom community and its members.

[18] At one point, I considered using computer software such as NUD*IST to aid in this process, but I found it too cumbersome for this type of analysis.

Chapter Five: The Bayview Classroom

Belinda's classroom was a complex environment before the additional technology tools were introduced. In this chapter, I shall describe those characteristics which identify the primary components of the Bayview classroom. These include the physical environment of the room and its immediate surroundings; the role of Belinda as teacher; and the students and their roles as members of the collective. Then I will describe in detail how events unfolded in the classroom, in the context of emerging themes of complexity. Chapter Seven will be devoted to discussion and analysis of classroom events using the complexity framework.

Description of the Bayview classroom environment

As mentioned in the preceding methodology chapter, Bayview Elementary School is a relatively small school of only about 250 students in grades kindergarten through five, with 25 faculty and staff. Class sizes are correspondingly small, with at most between 20 to 25 students. A new principal, Margaret Henderson, with many years of administrative experience, came to Bayview at the beginning of the research year. She was welcomed by the school community as a 'breath of fresh air' after five years under a more autocratic principal. Margaret quickly worked to assure teachers that she would do all she could to support them in their classrooms, rather than trying to directly control them. This stance proved to be a key feature of the school as Belinda was then relatively free to develop her curricula as she saw fit.

The 3rd floor classroom was a 4th/5th grade multiage environment, consisting of 24 students; twelve boys and twelve girls. Six of the students were 4th graders who were placed in this class by the team of intermediate teachers on the basis of their expected ability to mesh with the 5^{th} graders socially and academically. All students were native English speakers. The class population was quite stable during my research period of August 2002 through January 2003, with one student departing and one arriving. This stability allowed classroom members (including the teacher) to get to know each other over time, and to acquire a degree of comfort and familiarity. Most students had been at Bayview for many years. In the Bayview classroom, and school community in general, a stable population had historically provided for continuity and a sense of shared endeavor. This learning community perspective had endured in spite of a period of contentious administration with the previous principal, who was considered by faculty and staff to be overly ordered in her leadership style. The students, while not highly diverse in terms of ethnicity or socioeconomic status, brought with them to the classroom community a multitude of experiences and resources.

Physical Description of the Classroom and its Immediate Surroundings

It is important to describe the physical environment of the classroom community, as the structure directly contributed to the flow of learning activities. The relatively flexible arrangements, allowing for movement of students from area to area as tasks and goals required, provided a degree of openness in this complex system.

Belinda's classroom was fairly large and bright, with high ceilings and tall windows allowing for a beautiful view of the bay. Though Bayview is an older school, the rooms are well maintained, with the possible exception of the threadbare carpets and temperamental heating system. See Figure 5-1 for a diagram of the classroom. In order to facilitate group work, students were seated in table groups of between four and six students. Belinda's desk was situated in the far front corner of the room, near the windows. The front area of the classroom was relatively clear, with a rocking chair and rug placed there, and room for all students to sit on the floor. The whiteboard at the front was relatively open in the center portion, with the daily schedule posted on the left side. This daily schedule usually consisted of a sequence of anticipated events, with specific times attached only to those items that required interaction with the school schedule; e.g., recess, lunch, physical education, etc. With few time constraints placed upon the activities of the classroom, events and lessons were allowed to unfold and emerge through the day, with limited need to watch the clock. The rest of the whiteboard space was often covered with notes, posters, work samples, etc. There was an overhead projector on a cart, along with a television on another, larger cart, which was hooked into one of the student computer stations in the corner. This allowed Belinda and the students to see what was on that computer for demonstrations, presentations, etc.

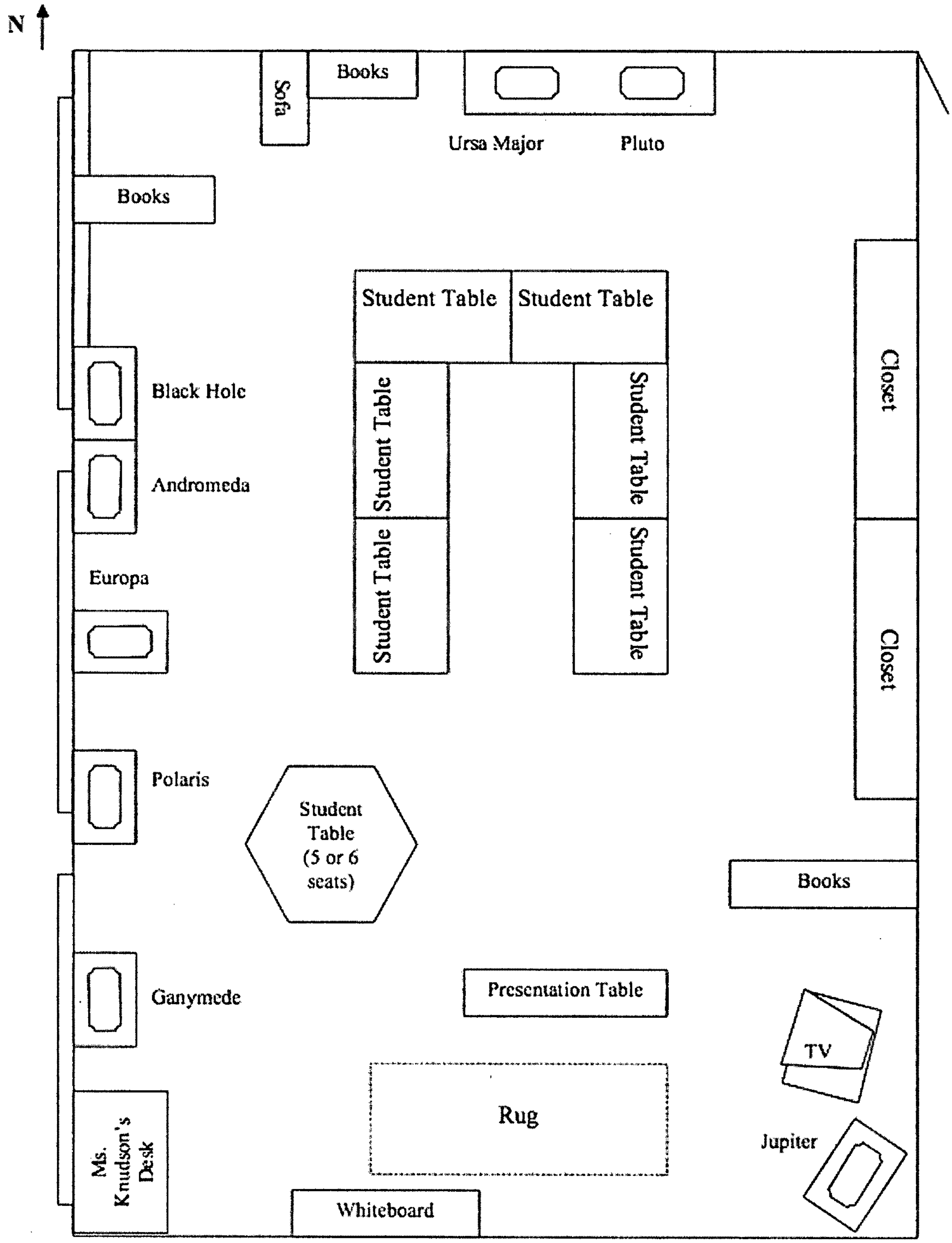

Figure 5-1 Diagram of Bayview Classroom

Around the room were various shelves and cupboards for storage of materials, books, calculators, etc. The one thing missing was a cloakroom for coats and backpacks, which most other classrooms in Bayview contained. In the back corner of the room by the windows was a reading corner with shelves and a comfortable sofa. The sofa was a desirable place for the students to be, which induced them to come up with a system for sharing it as the year began. It is important to note this self-organizing event; Belinda did not make this system and enforce it; the children, acting as a community, did.

I will describe the technology tools available in more depth in the following chapter, but I will describe their physical placement here. In the classroom there were eight Gateway desktop computers with large monitors. These computers were placed on regular stationary desks and tables at the periphery of the room, with various Ethernet cables and power cords draped from them to the walls. In order to reduce clutter, no chairs were placed at the computers, rather students brought them over from tables as needed. There was no separate or distinct area for the computers; they were dispersed throughout the room as space provided. When two to three students were working on a computer, the space could become rather congested; but for the most part, students dealt with this quite well. The crowded placement of the computers could be inconvenient at times, but having them so close together allowed for a high degree of spontaneous member interaction in this complex community. Belinda also had a Gateway laptop computer that she very seldom used. When I arrived, she voiced a desire to use it more this year. I located an additional Ethernet port available near her desk, so we hooked it up. This effectively added another computer to the room, as Belinda did not retain exclusive use of the laptop. Rather, she allowed the students to use it whenever she was not.

Belinda's classroom was right across the hall from the Media Center, or the library, as everyone called it. On the far side of the library was the computer lab, with 24 computers arranged around the perimeter of the class area. In this school district, each elementary school had one computer lab of a standard size, regardless of student numbers. As Bayview had a student body of half the size of some of the larger schools, that made it much easier for Bayview teachers and students to access their computer lab. With only twelve classes, it was relatively easy to accommodate everyone who wanted to schedule time. Also, the room was often free, which meant that Belinda's students could use it. It was just a matter of walking over to check its status. This ease of access to technology as needed allowed for self-organization of class members.

More importantly, also present in the library was a small area known as 'the stage.'. This little nook in the wall closest to the door contained four more computers. This area became key to the students as a 'slop-over' space; used when the computers were a bit too crowded in the classroom. The proximity of the stage, and my presence as a second adult in the classroom environment, allowed students to freely use these computers as needed; effectively increasing the amount of computers available for student use by more than 50%. Belinda and I asked only that the students let us know that they were going to the stage, so that we could circulate into that area as well.

This proximity to the library also meant that the Library Media Specialist, Seth Jacobs, was close by. Seth was the building technology support person, though he did not have complete control over, or knowledge of, all the computers, networks, drives, etc. School district technology personnel retained that control. However, Seth was a great resource to have nearby. As school librarian, Seth ordered a large number of books in the areas of science fiction, space exploration, and astronomy for the library collection; which was woefully inadequate at the beginning of my time at Bayview. We worked together to choose titles, with Seth ordering all that I suggested. Unfortunately, due to the slow process of ordering with a school district, most of these books did not arrive until after our project.

When I arrived in the classroom the week before school started, Belinda and I decorated the room with various astronomy and space exploration posters and photos, as this was to be our science topic for the next four months. We placed appropriate books and magazines in the reading corner. Most of these materials were mine, as I have a special affinity for space and astronomy. Though astronomy is a science topic, our intent was for it to be a theme woven through all subject areas as much as possible. Setting up the room this way would help to set the tone; a small example of sensitivity to initial conditions.

Belinda and her Role

As mentioned above, Belinda was a veteran teacher, but still quite young, with a small child at home. She was comfortable in her classroom, and had developed a real love for the upper elementary grades. One would think that her advanced degree in educational technology would have made her a technology expert, but that was not the case. Though increasingly comfortable with computers, she was still working on getting them integrated fully, and meaningfully, into her instruction. One of the reasons Belinda agreed to do this research project was because she wished to further her development in the area of technology; both the technical aspect and the pedagogical. In addition, though Belinda had been teaching science to her students consistently and enthusiastically over the years (somewhat an exception at Bayview and in the district), she wanted to learn more about how to integrate technology into science learning.

As she has become more confident in her practice, Belinda's classroom became more and more student-centered. In this context, with student-centered meaning that students exercise a substantial degree of responsibility for the topic taught, how it is learned, and for movements in the classroom and surrounding areas (Cuban, 1993). Belinda was not afraid to give away power and responsibility to the children. As she stated in our first formal interview, "there's a difference between power and control – you still have control of the classroom, you still set the structure on how things are being done, but you don't have to micro-manage…." (8/21/02 interview). Belinda's management style freed the children to pursue their own interests to a great extent within the curricular goals set by her and the district.

Belinda fully expected students to find information when doing research on the computer that was unknown to her; in fact she relished that experience and saw it as an advantage to learning as an open, collective, and holistic community. She found that process of learning fascinating, and a little scary:

> Because, as a teacher, am I supposed to know everything? Am I this sage? The knower of all knowledge? And, of course, I'm not. I know a few things, but I'm not going to even pretend to know everything there is to know about any subject. And it's always changing. But I think it's good for kids because it empowers them, you know, to be able to know something more than the teacher and to actually be able to back it up…then we kind of come together and learn together (8/21/02 interview).

Students truly can inform their teacher, and each other. Belinda saw it as her job to assist students in their search for information, and also to *let them struggle* for answers, rather than to merely distribute knowledge that she (or the school district or state) viewed as important. This struggle is important, as it is here that new knowledge formation can occur in the students; at times individually, but often in groups working together (Davis, 2006).

Belinda reiterated to me throughout our interviews that she was comfortable with change, and enjoyed the challenge of keeping up with new ideas and practices. She repeatedly described herself as "adaptable," and spoke about how doing new things kept her fresh as a teacher. In our August 21, 2002 interview, Belinda phrased it this way:

> I do really well with change. It seems like every year that I've been in education there's been so much change that I almost want it to slow down a little bit . . . but I have done a lot of reading about the change process and how you really have to be willing to embrace it and know that it is an opportunity for learning and I'm excited about it. It keeps me fresh and excited about what I'm doing, too. I'm not the kind of teacher that just pulls the old thing out that I've already done. I'd like to . . . sometimes I use that as a springboard, but every time you teach something, you think about ways you could change it to make it even better. That's just what you do when you're a teacher. You reflect. So that's just how I view my role: as part of the education system, being willing to change, good change, not just change because . . . throw the baby out with the bathwater or whatever . . .

However, she made it clear that change had to be purposeful, "because I really want my kids to come away with the most they can."

As I spent more and more time in the classroom, I observed that Belinda was not prescriptive in her instruction methods. I came to call her way of introducing a lesson the 'start the top spinning' method. In a typical lesson, she would get the attention of the class, usually with a bell. Often students would remain in their seats, but if the introduction was going to take a little longer than usual, or would be using the computer connected to the television, students would gather on the carpet. Belinda might start by asking a question, such as "what are some of the ways humans can explore space?" Questions were invariably open-ended; soliciting a variety of answers and discussion. Belinda was setting the question for discussion, keeping her goal(s) in mind, but she did not lead the discourse to a preordained destination (Iannone, 1995).

Other times, a new concept or idea would be introduced by reading a book aloud after lunch.[19] Then, the new assignment would be discussed with the students, with Belinda giving some guidance, or asking the students as a group to determine the appropriate criteria. Belinda believed strongly that the students needed to contribute to the expectations for a lesson or assignment. This self-organizing, emergent process helped to distribute ownership for the learning process to the classroom community as a whole; rather than the teacher holding all grading power. Then, as the students worked, Belinda and I would circulate amongst the groups, asking questions, or merely sitting with them, watching and/or assessing what was happening. During this time, Belinda expected that both of us would learn from the students, "what's working, what's not working, what problems they happen to have that we didn't foresee happening, or ones that we thought would happen that don't" (8/21/02 interview). In all my time in the classroom, I never saw Belinda lecture from the front of the room. This was not her style.

Working together as a classroom community was also a focus for Belinda. In order to do that, students were seated in table groups, and customarily worked in pairs or trios on the classroom computers. In the beginning of the year, Belinda assigned seats and computer partners so that she *and the students* could see how different people worked together. Later in the project, students self-organized; either by choosing research partners, or by letting the topic choice make the determination. Through the research period, students became more and more proficient with this shared work. In September, students needed some specific help

---

[19] As time went by, I began to do more of this reading with the children, while Belinda prepared materials for the afternoon's lesson.

with working together. For example, both Belinda and I reminded students to share their time on the computers, so that each person had the opportunity to 'drive.' But by October, most work proceeded fluidly between larger groups to pairs to individuals and back as the task demanded. Very little friction occurred between or among working groups.

Belinda's philosophy and style of teaching encouraged students to take responsibility for their learning, which worked well with this group of students. Belinda was always there as needed, and was quite adept at giving a 'nudge' toward a resource or strategy, rather than controlling all aspects of student learning.

The Students and their Roles

The students were not necessarily consciously aware of their roles as members of the complex, adaptive environment of the classroom. However, how they and Belinda interacted and established their community allowed for the emergence of such a learning system.

As I mentioned above, Belinda desired and established what she termed a student-centered classroom. She accomplished this in a number of ways, but primarily she proceeded as if she *expected* the students to be responsible for their learning. The onus was placed upon the students to seek answers to their questions. Of course, Belinda provided scaffolding in this process, or operated as an enabling constraint, in order to help maintain a productive balance between organization and randomness (Davis & Simmt, 2003). Belinda also worked hard to encourage students to work independently of the adults in the classroom; to remember to ask a partner, or another member of the class, before asking her (or me) for help. Over time this practice evolved, especially as we remembered to remind students to 'ask three before me' before they came to us with questions. As Belinda said, "I'd always had that kind of approach with kids – that you want to release them and give them the responsibility, but you kind of have to teach them to be responsible. You can't just expect it and not give them any support..." (2/23/03 interview).

With so much information accessible through the computers, Belinda was even more comfortable responding to a student question by saying, "How can *we* find that out?"; giving students the appropriate amount of freedom to spontaneously organize themselves and their knowledge (McAndrew, 1997). The key for Belinda was to let the students struggle for answers; not to step in and 'bail them out' when they had trouble finding information. Sometimes students would say they couldn't find information because "they just expected it to pop up on the screen" (9/10/02 interview), but then Belinda might nudge them with a helpful search strategy. Belinda's stated goal was to "let the kids drive a little bit more...so that interest continues to stay high..." but also to encourage the students to persevere and take responsibility for their learning and knowledge formation (9/10/02 interview).

Having an additional adult in the room allowed Belinda to work with small groups more often, during which she could guide the students in understanding difficult concepts. For example, when the class was exploring the Earth's seasons, Belinda worked with groups of four students and 'black box globes,' (as shown in Figure 5-2) composed of a globe mounted on its axis at a 23.5 degree tilt, with half of the Earth rotating through a dark box to represent night. The wheel at the bottom of the globe allows the learner to represent different dates on the calendar, which then rotates the globe to the appropriate tilt relative to sunlight received. Belinda related to me that at first she caught herself doing a lot of explaining to the children, but then consciously stepped back when she recognized that "learning for them came when I kind of stepped back and they started spinning...I just stood back and would pop in a question here and there" (9/10/02 interview). Though this is not an example of computer technology use in the classroom, this episode conveys how Belinda wished to guide self-directed and emergent understandings in her students.

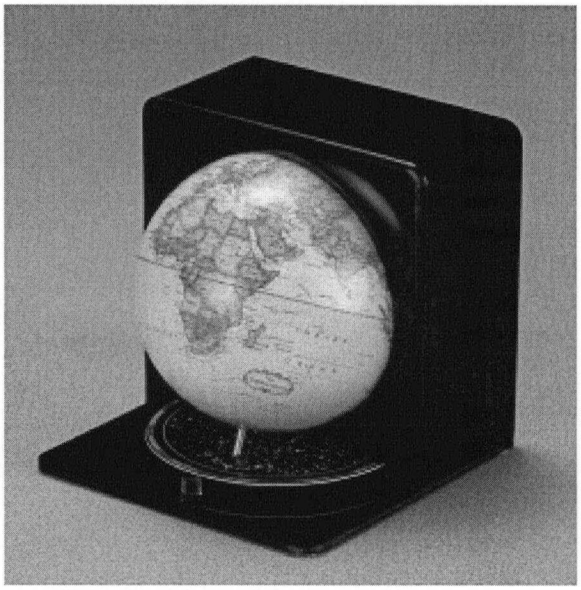

Figure 5-2. Seasonal Rotation Globe used in the Bayview Classroom (available at http://www.sciencekit.com/category.asp_Q_c_E_476853)

Learning in this technology enhanced classroom meant that students were expected to explore their interests within a relatively broad curricular area, but with an appropriate degree of self-direction. The computers provided an almost infinite range of primary, non-predigested information; not limited to materials the teacher provided; resulting in an open learning community. As Belinda said, "these kids are being raised to look at research in a different way (than previous generations). It's more complicated than just going out and getting the facts…you kind of have to cross reference" (11/16/02 interview). Students needed to develop skills to be discerning consumers of information, and to make their own decisions about trustworthiness of data. This again distributed more power to the classroom learning system as a whole, and away from Belinda as teacher.

As time went by, the students became more autonomous of adults in their work; but also took on more collective responsibility by helping each other with research. For example, when student pairs were researching various space exploration programs, soon all knew what each group was doing. This led them to provide information to others as it was found on various web sites. Belinda and I had considered posting a list of topics matched to groups, but we found that structuring was unnecessary. A pair who found information about the Gemini program while reading an Internet source about the Mercury program would share the Web address with the Mercury pair quite freely. These ideas didn't need to be funneled through the teacher, rather they were spontaneously shared as needed.

Towards the end of the research period, to help me find out more about how students viewed their research projects and the technology in the classroom, I interviewed each student individually about our experiences in the classroom (see Appendix B for sample interview questions). These interviews were semi-structured, which allowed the students to respond with short answers, or to engage in a full conversation with me. One of the questions I asked was about the research work that the students had been doing about space during the last few months. Many students answered with a simple, "I liked it!" However, others talked more. For example, Scott spoke about the freedom he had enjoyed in his projects:

> I really like having the computers because I can find information on just about anything if I know where to look! And it's been fun finding out about things I want to know about...not just things the teacher wants us to know...I've been able to do my own thing, you know? (12/10/02 interview).

Scott had been formally identified as a highly capable learner in 3rd grade, and blossomed in the freer environment of this 4th/5th grade classroom; taking more and more responsibility for his own learning.

However, another student, Mike, reported his initial discomfort:

> Well, at first I was excited about learning about space. I still am actually. But, I've had a hard time sometimes working on my own....also in groups. Sometimes I just didn't know what I was supposed to do next...what to do....where to look. The computers are great and everything, but there's sometimes too much information. *I guess I'll just have to learn about learning for myself* (emphasis added, 12/10/02 interview).

Mike was also a very bright student, but he often had trouble staying settled on a task; drifting both physically and intellectually. A topic would catch his interest for a short time; he would find all sorts of information, much of it too advanced for him; then get frustrated and look for another topic. Belinda and I worked with him often, *setting up structures* for lessons so he could succeed. In the end, Mike produced one of the most creative independent research projects in the class. He thoroughly researched the life and accomplishments of Werner von Braun, dressed in character for the Science Fair, and regaled all visitors to his desk with the story of Werner's life! Mike related well to the human side of science, which Belinda continued to capitalize upon through the rest of the year.

How Events Unfolded in the Classroom

Pre-arrival

In January of 2002, I approached Belinda about my potential research project. I told her that I was interested in examining how a teacher and students use computer technology when learning about science. Belinda was a Gates Grant recipient, and had received her computers in the fall of 2000.[20] I knew that Belinda regularly taught science to her students,

[20] These grants from the Bill and Melinda Gates Foundation, were given in the state to eight districts, and required districts to "reinvent" themselves and their schools to create standards-based *technology-enabled*

which was a rarity at Bayview as science was not on the statewide assessment at that point. These things made her somewhat different than the other teachers at Bayview, but also meant that her classroom would be a rich research environment. Though she had received computers through the grant, she was a district-funded participant, which meant she did *not* receive any professional development in how to best use her equipment for instruction. Belinda knew that I had a strong background in science, and was excited that she could have a 'science expert' in her classroom. As she stated later, "...I think that us working together will be a big support, because you will have someone there to talk through the plusses, the minuses, the what-ifs" (8/21/02 interview). We both agreed that this project would not only help me with my research, but also would help her in the classroom, and support her students in their learning process.

In the spring of 2002, Belinda and I had various conversations about how we would like to begin in the fall. At that point, we believed we would have a class of 4th graders. For that reason, Belinda chose Water as the science topic we would explore, as that was one of the topics recommended, not mandated, by the district. As we discussed our work together, we brainstormed lists of possible ways to proceed, and also explored my role in the classroom. Belinda was quite open to letting the project unfold and emerge as we went along; perhaps even more comfortable than I was. Upon reflection, I see now that Belinda was secure in allowing events to develop in her classroom, with general guidance from her, but not under strict control. However, being a less-experienced teacher, and a new researcher, I was more anxious about how things would progress. We agreed that my role would be that of researcher first, but that I would also act as a teacher at times. We planned to start working together in her classroom the week before school started in August. During

---

learning environments. The purpose of these grants was to support districts and schools in their reinvention efforts at all levels, kindergarten through high school. The Bayview district received $4,492,800.

the summer, in addition to preparing for the practical aspects of research, I read a great deal in the areas of a) technology integration into science instruction, b) teaching and learning about water, c) participant research, and d) complexity theory. I also arranged to borrow various pieces of technological equipment appropriate for our planned water unit from my university science education center.

Planning ahead

In August, Belinda and I learned that due to a change in enrollment, the class would be multiage 4th and 5th grade, as described earlier. As the majority of students would now be 5th graders, we changed the topic to astronomy and space exploration; or as we simply called it, Space; a topic recommended, but not mandated, for 5th grade by the district. Only one basic kit, 'The Moons of Jupiter,' produced by GEMS at the Lawrence Hall of Science,[21] was provided by the district. We were not unhappy with this change. On the contrary, we welcomed it as we knew that students were always interested in this topic, and Belinda had taught in this area previously. In addition, I was considered to be a 'space nut,' and I had a large amount of resources to draw upon. The lack of direct external control of our curriculum by the district or state allowed us to structure and organize ourselves to a great extent, a prominent feature of complex learning systems in which order arises through member interactions.

During our week of planning, we set up a loose calendar of what we intended to do over the next four months. However, we kept the schedule flexible so that we could respond to collective student interest. This is an important point. Although there were monthly

[21] GEMS Kits are marketed through Carolina Biological Supply. The Moons of Jupiter, which is based on the Galileo and Voyager missions to Jupiter, can be found at: https://www2.carolina.com/webapp/wcs/stores/servlet/ProductDisplay?jdeAddressId=&catalogId=10101&storeId=10151&productId=45045&langId=-1&parent_category_rn=&crumbs=n

topics, Belinda very deliberately left exact dates out of the process. Instead, we explored the themes recommended in the National Science Standards[22] and state Essential Academic Learning Requirements, and sketched out a list of topics we believed the students would enjoy and benefit from. As shown in Table 5-1, we were to begin close in with the Earth and its seasons; move on to the Moon; then the solar system; space exploration; and then close with independent research as desired by the students. We fully expected this calendar to change, and it did.

[22] The specific National Science Standards for Grades 5 through 8 in earth and space science can be found at http://fermat.nap.edu/html/nses/6d.html#es

Dates	Topic	Sample Lessons (science)	Planned technology support
August-September	Moon and its phases	Ball & stick model Observation	Online animations and research; Starry Night
	Seasons	Globes (standard and shadow boxes)	Online animations and research
September-October	Objects in the solar system	Various worksheets (Please-Ex-Planet) and readings Moons of Jupiter (kit materials) Planetarium field trip	Planet travel brochures created using Publisher; online data gathering; Classroom Excel spreadsheet construction for data gathered
September-October	Scale of solar system	Modeling with produce; Outside scale model	Starry Night modeling; other online animations
October	Space Exploration (manned and unmanned)	NASA videos Rocket construction Toys in Space Mars colonization	PowerPoint projects on specific programs, i.e. Apollo. LiveChat w/ astronaut
November-December	Independent Research (student choice of topic)	Project construction and presentation	Online research; PowerPoint if desired
Throughout	Varied- as desired by students	As needed	Online research

Table 5-1. Expected progression of events

During this planning week, Belinda and I discussed formally (through interviews), and informally, our respective pedagogies of teaching. As I had expected, we found our views to be quite similar. Both of us denigrated 'inch-deep, mile-wide' curricula as meaningless and insubstantial, and believed that student construction of knowledge and learning occurred over time with repeated exposures to materials in different formats and contexts. We were both quite comfortable with spending nearly four months in the classroom with an astronomy and space exploration focus; and this was enabled by an administration which did not demand uniformity of all curricula and instruction. To that end, we planned as many lessons relating to the topic as we could across *all curricular areas*.

For example, in Mathematics we would explore estimation and large numbers in an attempt to enable the children to comprehend some of the large distances involved in space travel and the solar system. In Language Arts, Belinda would focus on creation and astronomy myths of cultures around the world. Students would also write their own constellation myths, haikus, poems, and other stories. As mentioned previously, the school librarian, Seth Jacobs, ordered a large number of science fiction books; though these did not begin to arrive until December. However, Belinda still proceeded with a literature unit about science fiction in January. For Art, students would create constellation drawings, paintings, and sculptures. Belinda also let the Music and Physical Education teachers know about our space theme, and to some extent they worked that into their time with the students. Before long, all staff at Bayview knew that our room was the 'Space Room.'

In Social Studies, as mentioned previously, Belinda planned to feature myths from different cultures. However, as the class moved into the topics of exploration, students would be encouraged to think about the costs and benefits of exploration to society. For example, in one lesson, student groups would be asked to prepare for a colonization effort on Mars. Decisions about who should organize and travel on such an expedition would need to be made, along with what equipment and materials should be brought along. As it turned out, one group continued this project long after I had formally left the classroom; working with how such a new colony would grow, change and be governed. It was no coincidence that Belinda began an extensive unit about historical human exploration of the Earth after we finished this project.

In August, Belinda and I discussed what role we expected technology to play in the classroom. Belinda really wanted to focus on the research cycle with her students, and saw technology as a support for curriculum objectives she already had in place. Technology would "help with the research cycle and getting kids to partake in actual research topics that they really care about and are interested in…to be able to expand the depth of the curriculum objectives that we have…I think that technology is a way to really challenge kids" (2/23/03 interview). She wanted technology to be a *part of what was already happening* in the classroom; not to be an experience where students just 'go do computers.' She strongly believed, as related through our discussions, that one should never do technology for technology's sake. This would allow for the emergence of technology as an imaginative extension of the learning environment, not an 'add-on'.

Initially, I was concerned that we would not have more varied technology embedded in the project. I had hoped to be able to utilize a broader range of technology tools. For example, when we had expected to study water, I had arranged for a set of handhelds to use for water analysis of a local creek; with data being uploaded to the Web for sharing with other students in the district. As we planned for Space, students would primarily be using computers for research, exploration of topics through Web animations and other tools, and for creation of products for an audience. As it turned out, this use of technology was a very rich and rewarding experience for Belinda, the students, and me. I will delve into the specifics of how our use of technology developed in the following chapter.

In the Throes as School Begins

Both Belinda and I discussed how important it would be to set the appropriate tone for our learning community from the beginning, as we knew that how we launched our project would have great influence over later events. On the first day of school, Belinda introduced herself to the children and talked quite openly about her style of teaching. She told the students that she expected them to become more proficient at research, and that they would be doing a lot of that research together. There would be very few, if any, individual tests. She told them that 'all the people in the room' were there to learn, and to help others learn. That included the students, Belinda, and me. Having the computers in the room meant that students would be able to investigate a wide variety of topics, and Belinda specifically said that she (and I) would serve as guides, not directive leaders, for the children as they explored.

One of Belinda's first discussions with the children introduced basic classroom rules that would support learning. Many teachers now ask their students to determine the rules of behavior in their classrooms, rather than merely posting his/her own. However, Belinda asked the students to brainstorm in their table groups about what sort of environment supported learning for them, and then write down a list to share with the class. A lively discussion about noise level, sharing of resources, politeness, respect, and use of time ensued. In the end, a poster with 'Ms. Knudson's Class Guidelines' was created and hung on the wall by the children. This list was revisited regularly throughout the year, with a few changes and amendments added as needed. The Guidelines were not static, but rather emerged, evolved and changed over time.

This poster contained many of the usual choices, such as 'no put-downs,' but also one which merely said '**take risks**.' This concept was one that had emerged in the talks between Belinda and me. Both of us had discovered that we really had no fear of how things would unfold in the classroom. Part of this was due to the fact that there would be two of us to support student learning, but also we felt that we would easily learn from our mistakes. We knew that technology tools would sometimes fail us and the students, and that not all of our ideas would fare well in implementation. But, we wanted to see what would happen and work with that. One of the ideas brought forward by a student group was that students shouldn't be afraid to try new things. Belinda eagerly jumped on that, and talked a little about taking risks in learning, and in relationships. The students were quite taken with being referred to as risk-takers, and often used the phrase throughout the year. This served them well as we began the research process.

As I have pondered this research and immersed myself over time in the data from this classroom, the **theme of risk taking** continues to emerge. Belinda and her students were comfortable trying new things, both with technology, and with curriculum. Students became more and more comfortable with this idea; making decisions to research topics that might have seemed forbidding to the typical ten or eleven year old (interstellar gas jets come to mind). Having the computers as a resource meant that information about virtually any topic could be found. However, students then had to interpret the information so that it made sense to them. Reading for information and understanding proved to be the challenge for many students, as I shall explore more fully in the next chapter, which focuses more directly on the technology experience in the classroom.

In this chapter I have described the Bayview classroom in physical, classroom management, pedagogical, and curricular terms; paying special attention to those aspects which exemplified this complex learning community. In the following chapter, I turn my attention more specifically to technology tools and their role in extending the learning environment. I also explore the ways in which Belinda and her students engaged with technology, allowing for the emergence of powerful uses within the structures of the classroom.

Chapter Six: Technology as a Means of Research

In this chapter, I begin by exploring more in depth the technology tools available in the Bayview classroom, along with the few pedagogical guidelines provided by the school district for their use. Then I provide a brief description of the students' and Belinda's background in technology; followed by a descriptive narrative of the specific projects in astronomy and space exploration undertaken by the classroom community. In the latter half of the chapter, I delve into how Belinda and the students interacted with the computers, and what powerful uses of technology emerged in the classroom; accompanied by a discussion of some of the technological difficulties encountered.

Technology Present in the Classroom

As stated previously, there were nine computers accessible to students in the Bayview classroom. With 24 students in the class, this resulted in a student to Internet-connected computer ratio of 2.67:1, *when all computers were present and functioning*. For the year of my research, 2002, the U.S. average was 5.6:1, while the Washington state average was 5.8:1 ("Technology Counts "). These state and national figures take into account all computers available in a school, including those in labs. When the nearby computer lab and 'stage' computers were taken into account, it would be accurate to say that this was a technology rich environment.

Most of the classroom computers ran on the Windows 2000 operating system, though two were still using Windows 98. The basic Microsoft Office suite was present, along with Internet Explorer for Web browsing, Outlook for e-mail, Paint, and Microsoft Publisher. A standard keyboarding program and Accelerated Reader were also loaded on the machines. No movie or animation software such as QuickTime™ or RealPlayer™ were present, which led to some difficulties that are discussed later in this chapter. Two of the computers had speakers, but the rest were silent. All were networked to a black and white laser printer in the classroom, and a color printer in the computer lab. A scanner was available for student and teacher use in the computer lab.

I also brought in my Apple iBook when I was in the classroom. I was able to hook into the Bayview network initially, but then lost that capability due to new firewall protections put in place by the school district. On that iBook, I had recently installed the Professional version of Starry Night™ software.[23] I often left my iBook out on a desk near the classroom computers, with a Starry Night™ solar system simulation running on it, so that students could explore as they wished.

Belinda did not have a document camera or LCD projector while I was doing my research. However, when I was visiting soon after our project was over, Belinda told me that she had heard that there was an LCD projector somewhere in the Bayview building; as every school in the district had been provided with one through the Gates Grant. But, none of the teachers had it in their classrooms. We embarked on a quest to find it, and discovered it in its box in the back of a cupboard in the textbook and curriculum materials storage room. Seth Jacobs, the building Library Media Specialist, was particularly pleased we had found this expensive piece of equipment! Belinda and I set it up in her room and connected it to her laptop. By the time I visited again, Belinda had removed her overhead projector and television monitor from the room completely.

Belinda also did not have a digital still or video camera in her room. I brought in one of my digital cameras to document what was happening in the room, and soon left it there all of the time so that Belinda could use it, even when I was not there. I also brought in my

---

[23] Starry Night software can be explored at http://www.starrynight.com/

digital video camera, but I did not leave it there when I was gone. Soon after I left, Belinda arranged to have her own digital camera in the room by checking one out from district support. These tools were not intended for student use at that time, though that would have been another rich area of research.

After two years, this level of available technology was no longer 'new' to Belinda, but represented a rich, though underutilized, resource. The computers, though certainly now part of the regular equipment of the classroom, were not yet a natural extension of the learning environment. Belinda's technology was supported financially, but at other levels support could best be characterized as benign neglect. Her discovery and use of the LCD projector was accidental; resulting from a rumor of its presence within the building. She had not been told about the equipment loan program through which she eventually borrowed the classroom digital camera. In some cases, this freedom and lack of structure operated as enabling constraints, allowing Belinda and her students to self-organize; to experiment with technology integration, unfettered by district directives. In others, as described later in this chapter, district restrictions resulted in the loss of learning experiences for students. However, the general lack of communication between district personnel and Belinda caused some resources to be unused.

The Technology Context of the School

The Bayview school district was quite advanced technologically; both in equipment provided and continual software upgrades. At least one computer was placed in each classroom in the late 1980s, though teachers with a higher interest received more through various programs and grants. By 2000, computers in all schools were equipped with high-speed Internet connections. In Bayview school in 2002, each teacher had a personal computer in her room.[24] Every primary classroom had two additional computers, though due to space considerations, they were connected in the hall outside each room. Intermediate classrooms contained two or three computers as well. Also, one other intermediate teacher had been a fully-funded and supported Gates Grant recipient; meaning that she had eight computers in her classroom for student use. As mentioned previously, a school computer lab with 24 computers was available for scheduling by teachers and Seth Jacobs. From early grades, students learned keyboarding and other computer skills. The Bayview school district Technology Plan contained five broad goals for students:

- Understand basic technology operations and concepts
- Use technology responsibly and ethically
- Use technology to communicate effectively and creatively
- Use technology for thinking, learning and producing
- Use technology for research, problem solving and decision-making.

The full Plan document of 95 pages is quite detailed and specific about technology experiences for students at each grade level; ranging from specific software skills to be taught, to basic troubleshooting with balky equipment and applications. If all students became adept in these skills, this would provide for a quite consistent and uniform background.

However, as all educators know, having a plan and equipment in place do not guarantee effective, or any, use. Beginning in kindergarten, all Bayview students received computer instruction from the Media Specialist in the lab once a week, with training varying by age and skill level. These sessions, along with providing keyboarding (typing) instruction, directly addressed the goals in the district Technology Plan. For some students,

[24] All teachers at Bayview in 2002 were female.

this was all the work they did on school computers, as some teachers did not utilize them more. In other classes, teachers and students were more active. This disparity resulted in students receiving a varied degree of computer experience, and therefore entering Belinda's classroom with diverse skills and abilities.

Setting the Tone

As the school year began, we soon found that it was difficult for us to distinguish one computer from another. For example, one of the computers was having technical difficulties and a student, Gabriel, wanted to tell me about it so I could investigate. When I asked him which one it was, he tried to tell me by saying it was 'the one back in the corner.' However, there were three computers back there, so Gabriel ended up just taking me over there to look. The next day, when I was taking part in a regular class meeting with Belinda and the students, I brought this problem to the group. I had a solution in mind, which was to name and label the computers, perhaps with astronomical names, but I wanted to see what the students would say. The first suggestion was to number them, but the students thought that would be too boring (and just like the computer lab). Another student, Chloe, suggested that we name them. Luke immediately chimed in with a suggestion to name them after 'space things' since we were doing research about space on the computers. The group immediately accepted this suggestion. So, the children came up with names, and then created and printed paper tents with those names to be placed on top of each monitor. The chosen names, all naturally occurring objects, were Andromeda, Black Hole, Europa, Ganymede, Jupiter, Pluto, Polaris, and Ursa Major.

I was pleased that I had not just barged in with my suggestion from the beginning, or worse yet, labeled the computers myself. Though this was a small event, it is an example of the complex themes of self-organization and shared power amongst all classroom members.

Within the supportive structure of the regular class meeting, we had provided enough flexibility so that the students would come up with a solution; we had allowed the answer to emerge from them.

As discussed in the previous chapter, neither Belinda nor I wished to overly direct the development of this learning environment. Technological tools would serve to expand the collective classroom learning environment and its members. We would not be limited to either Belinda's or my space teaching materials, which had been used before. Technological tools, and the human members of the system would open up this complex classroom, bringing in new information and perspectives throughout the year. However, Belinda and I also needed to provide an environment that would nurture these emergent practices. To that end, access and ease of use for the computers would be maintained.

Belinda's Background in Classroom Educational Technology use

Belinda was a district-funded participant in the Gates Grant Program, which meant that she received the equipment, software, and Ethernet connections; unfortunately she did not receive any professional development to go along with them. Fortunately, Belinda was not afraid of technology, and also held a Masters Degree in educational technology from a small university in a nearby metropolitan area. However, I soon found that Belinda really did not have a lot of technological background, in spite of her advanced degree. This did not necessarily serve as a hindrance, as Belinda was quite willing to take risks; to experiment with technology and pedagogy; and see what may emerge.

We explored Belinda's technology background via a formal interview in August of 2002. In Year One of the Gates Grant, she was faced with the challenge of using the computers 80% of the time, per the grant requirements. However, this did not mean that 80% of instruction had to happen on the computer. Rather, it meant that they should be up and ready for any use 80% of the time.[25] This grant requirement functioned as an enabling constraint, encouraging Belinda to use her new tools, but not directly prescribing exactly how that was to occur. Belinda described the use of the computers that first year (2000-01) as "kind of hit or miss" as she worked to structure her previous materials and curriculum "so that kids were using the computers" (8/21/02 interview). Often, she found herself using technology for technology's sake, which she didn't prefer. During this emergent year, Belinda worked with various grouping strategies so that two or three students could share one computer for a task. Students also had to learn what Belinda described as 'computer etiquette,' i.e., logging on, logging off, keeping equipment clean and dusted, etc. Students worked a lot with word processing, especially with Publisher; making calendars, brochures, and cards. However, even though Belinda's main focus was management of this new resource, she said that she still "let the kids drive a lot of the instruction that first year too – things they found interesting." She and her students also began exploring the Internet and information search strategies, often through specific tasks from Belinda such as "go to this website and find out this." This was the beginning of Belinda's continuing focus on using the computers to develop research skills with her students. Belinda's student-centered approach in "let (ting) the kids drive a lot of the instruction," which encouraged decentralized control in the classroom members; stands in opposition to the more teacher-directed tasks of searching for specific information. These ways of using the computers were discovered by Belinda and her students together, a sign of emergent practice.

Throughout all of our interviews and conversations during the year, Belinda often came back to the theme of using **models** with the children, and of modeling her strategies and expectations. Beginning in that first year of the grant, she regularly used the television

[25] Note this requirement also meant that the district had to provide support to ensure 80% usability. However, in this case the district did not fulfill this condition.

monitor connected to the student computer (Jupiter) in the front corner of the room. On this monitor, she could easily show children how to navigate to a web site, or to make a product using a piece of software. Also, Belinda was careful to have students share what they were doing through this system. She felt that the large monitor really helped her visual learners. The idea of *modeling* on a computer, but also with physical items, was a recurrent theme throughout Belinda's pedagogical approach.

In Year Two of the Gates Grant, Belinda began to focus even more on the research cycle with her students, by having them explore different projects where the "kids would be answering a big question." She differentiated between 'skinny' and 'fat' research questions, with fat questions being ones that could not be answered quickly, and requiring a large amount of information to answer. These types of questions often had more than one answer as well. In this year, she also studied astronomy with her students, attempting to "marry the scientific process with the research process." She began to experiment with longer-term projects, with component tasks to accomplish each day. She tried to incorporate both group and individual work in the projects. Also, it was in this year that Belinda really began to realize that the computers and Internet resources enabled students to do far more than a basic report. The students could be expected to produce a synthesis of information to support a position, rather than "just spewing out facts." Belinda believed that having the students complete and present PowerPoint™ presentations increased their depth of learning as "…when they are up there sharing I know that they've learned it, because it doesn't sound like an encyclopedia talking – they're putting it in their own words. They are able to synthesize what it is – they are answering *their* questions" (8/21/02 interview). This second year was also the first that Belinda experimented with having a 'Science Fair' in which students shared their work with the authentic audience of the school community.

However, Belinda still often thought of the computers as a separate resource, to be planned for and used on their own. When Belinda showed me her lesson planning book from that year, there were distinct blocks labeled as 'computer time' and 'use computers for this.' The computers were not yet a natural extension of the learning environment, though they were being utilized as the Gates Grant directed.

Year Three of the Gates Grant was our research year. Belinda was eager to develop use of the computers even more in the classroom through our work with the students. Her stated goal for our project was to work with "science and how technology can deepen the learning that is happening in the room" (8/21/02 interview). Belinda wished to teach technology in the context of the curriculum, and not just 'go do computers.' She believed that technology "enhances student learning by heightening the level of questioning that they have. It's very motivating for them. I think it has taken the level of questioning and understanding to another level, whereas if it was just books and groups of kids talking or something, there wouldn't be those opportunities" (8/21/02 interview). Belinda (and I) wished to explore how to make the computers a natural tool, embedded in the everyday learning experiences of the classroom learning community.

Student Background in Technology use

At the beginning of the year, I administered a written technology use survey to the students (see Appendix C), 23 of whom completed it. My goal for creating and administering these surveys was to find out about home access, along with previous and current uses of computers. I surveyed class students about their familiarity with computers in order to gain insight into their readiness to utilize technology in the classroom. Of the 23 students who responded, 20 reported that they were either very comfortable or comfortable using a computer (three students did not make a choice). As can be seen in Figure 6-1, most students had a computer at home with Internet access.

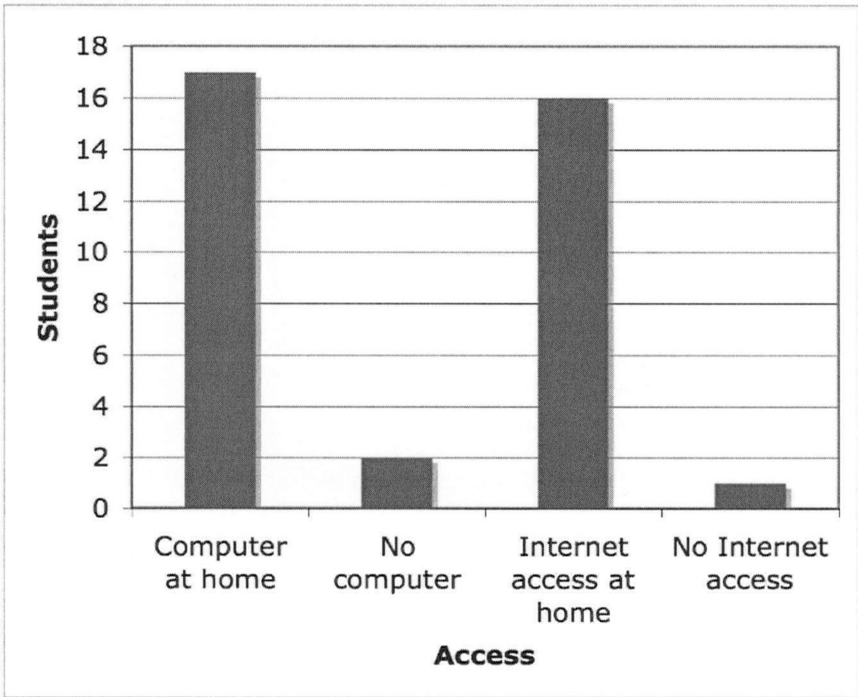

Figure 6-1 Student computer and Internet access at home

For those students who had access to a computer at home, all reported using it at least once a week (Figure 6-2).

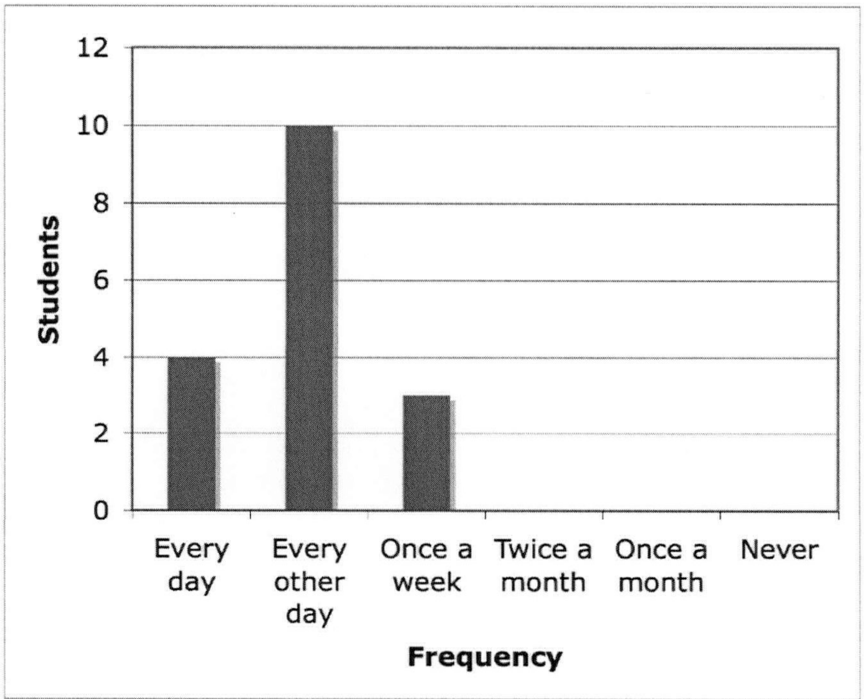

Figure 6-2 Frequency of home computer use

Those students reported using their home computers for a variety of things (see Table 6-1). Not surprisingly for students this age, games were the most popular activity. However, these were closely followed by school work and various kinds of research.

Uses for the home computer	Number of students
Games	15
School work	12
Research[26]	11
E-mail	8
Fun	4
Chat rooms	2
Word processing or typing	2
Shopping	2
Instant messaging	1
Making cards	1

Table 6-1. Student use of computers at home

Students reported starting to use computers in school at an early age, as shown in Figure 6-3, though many commented that they weren't sure exactly when they started, they "had just always been around" (student comment on survey). When Belinda and I discussed technology in our formal August interview, I asked her about student practice with technology. We had been talking about her practice with technology, so she responded with, "but, in a way, to the students, they probably have a much different approach because they have always had them (computers) in the classroom. Teachers have had to adjust to having them in their classrooms" (8/21/02 interview). As time goes by, and computers become a

[26] The word 'research' was a poor selection on my part for the survey. The term could be construed as scholarly research, but to a ten-year-old child could also mean research about skateboards.

given component in the classroom for students and teachers, the way researchers examine their use will adjust as well.

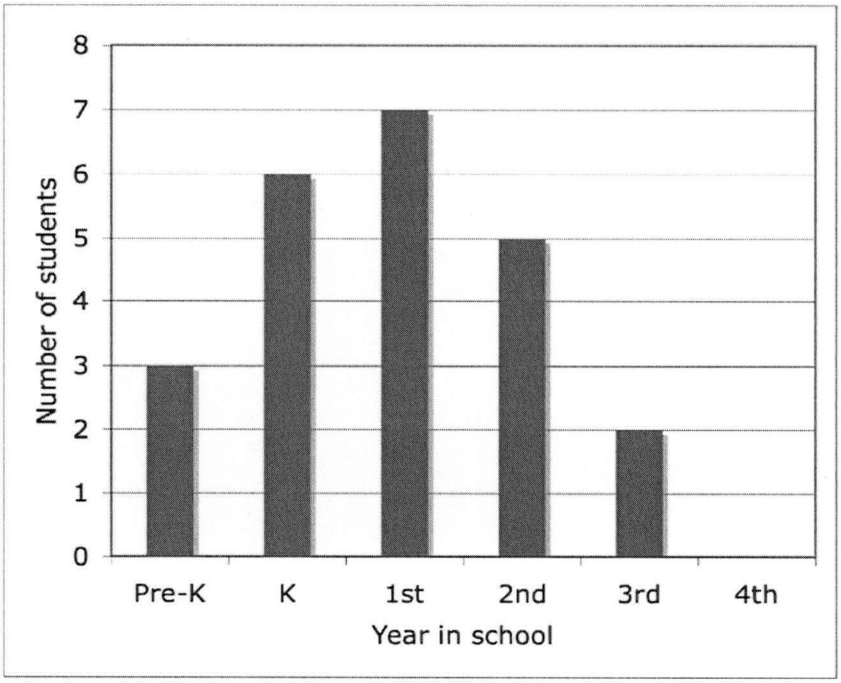

Figure 6-3 Beginning of school computer use

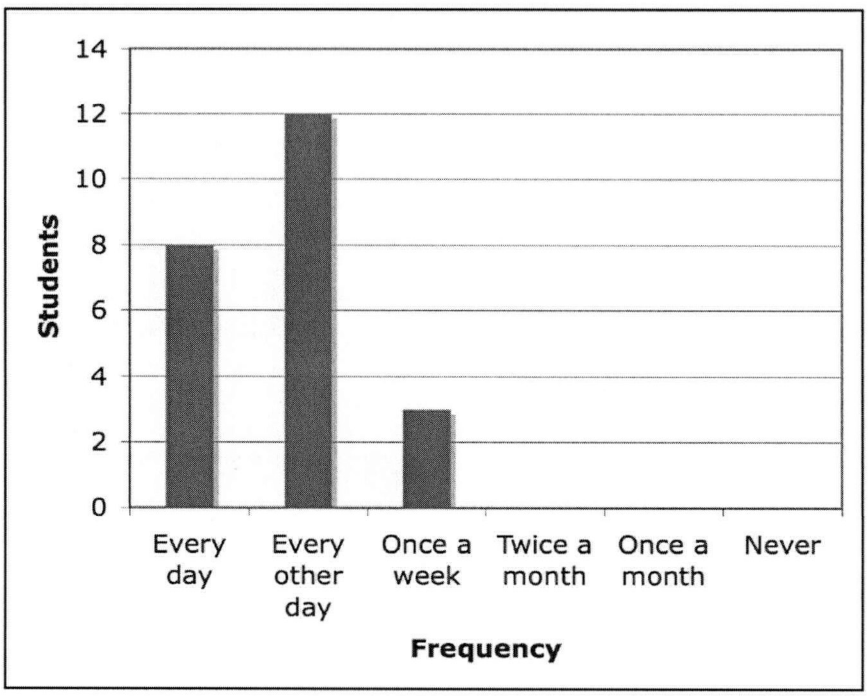

Figure 6-4 Frequency of school computer use

Not surprisingly, students reported frequent computer use at school, as illustrated in Figure 6-4. As mentioned previously, the Bayview school district was quite advanced technologically; providing a large number of computers, resulting in a low student to computer ratio. This ratio in turn afforded a high level of opportunity of student use.

In general, the students in Belinda's classroom had high access to computers at school and at home. Computers were seen as a natural component of their lives, and were used for a variety of recreational and educational tasks. The survey data indicated that most students would be able to navigate relatively easily on the computer, and also be familiar with web browsing and productivity software tools. Native Bayview students had received keyboarding instruction beginning in 1st grade, so most would be effective typists. These basic and similar student abilities provided for internal redundancy in the learning system, hopefully allowing flexibility of response to the use of technology. However, as not all students had an identical history with computers, there was also internal diversity in Belinda's classroom. We would now be able to explore the development of technology tools as a natural extension of the learning environment, taking into account all of the components brought into this open classroom community.

How Events Unfolded in the Classroom

World Wide Web Navigation

When we began this research project, most of the students appeared quite comfortable using the computers. They were easily able to log on, open applications, and surf the Internet in basic ways. However, though students could use Google™ to search the Web, they often had trouble choosing the search terms that would help them to find the information they needed. Also, when faced with a list of possible hits for their search, it was difficult for them to determine which sites on the list would be most helpful.

After a couple of days in the classroom, Belinda and I realized that the students had some basic skills, but needed more. For example, when we directed a student (David) to save a particularly helpful webpage in the Favorites (bookmarks) of Internet Explorer™, he had no idea about how to do that. We had noticed this weakness in other students, so, after lunch that day, we gathered the students for a mini-lesson on the rug in front of the computer which was hooked up to the television monitor. I had previously placed a few appropriate space sites in the Favorites list, so I was able to demonstrate how to navigate to those. Then, I did a search through Google for sites pertaining to solar flares (the Sun was in a particularly active phase at that time). Using the list of suggested sites from Google, I modeled how to make decisions about which ones to visit. When we found a particularly good example, I asked a student volunteer (Abby) to come up and show us how to save it as a Favorite. Once we had done this, there were many comments of, "oh, that's how you do that," or "I always wondered how you could do that."

When Belinda and I were discussing the day after school that afternoon, we realized that many students didn't know as much about Web navigation as we had believed. In order to make things easier for the children, I offered to set up a basic folder of Space Favorites on all of the classroom computers. I would choose about fifteen Favorites related to various aspects of the solar system and space exploration, and then let the students know they could add any particularly useful sites they discovered in their research. This proved to be very helpful, and the Favorites list on all of the computers grew at a high rate throughout the project. Later, I learned how to export and import these Favorites to shared computer drives, which allowed them to be easily moved from one machine to another. This enabled me to place the Favorites on the computers in the computer lab as well; after I showed Seth Jacobs (the Media Specialist) how to do it.

The technology tools were able to provide a large amount of information in response to the students' questions. However, the children found it difficult to distinguish between useful and useless links and data. Students would need assistance in developing their skills in discerning the value of information; in addition to organizational strategies such as Favorites. Our adaptive learning community would need supportive structures in order to continue its evolution.

Curriculum Choices

In the previous chapter, I shared a table of our planned sequence of Astronomy and Space Exploration subjects in the classroom (see Table 5-1). These broad topics would include Earth's seasons, lunar phases, solar system objects, and space exploration. There were limited curriculum materials provided for these topics by the school district; allowing for a high degree of autonomy in the classroom. Therefore, it was up to Belinda and me to make initial decisions about what we wanted to do; then to support self-organization of the community as we moved into the school year. When we made our original plan, we fully expected that it would change as events unfolded in the classroom, which it did. The basic progression through the topics remained the same, however the details within these broad categories fluctuated considerably. The essential framework for our work involved varied hands-on lessons and observation experiences, supplemented with student research and simulations using computers. However, it would have been equally accurate to phrase this as the converse statement; research and simulations supplemented with lessons and observations. The research cycle[27] was of great importance to Belinda, and also figured prominently in the district[28] and state academic standards. Therefore, I shall focus for the most part on the research projects we did, using technology as a tool. Following is a brief description of each of the projects. Later in the chapter, I explore common themes that emerged from these projects.

Project 1: The Solar System

For this project, the students worked in groups of two or three as assigned by Belinda. Each group was charged to search for basic facts about one of the nine planets[29] (randomly chosen) in the solar system, using a modified 'Please Ex-Planet' worksheet. These physical characteristics included size, composition, temperature, distance from the Sun, length of day and year, etc. In addition, students were also asked to find out the mythological basis for their planet's name. Most students used the computer to find the information, but some also used the books and other resources I had placed in the classroom. These data were to be included in a travel brochure, produced using Microsoft Publisher, created with the purpose of persuading a traveler to visit their planet. These brochures were presented to the class, placed on the hall bulletin board, and also on the class webpage. Many students took liberty with facts in these brochures, in an attempt to make their planet enticing. For example, for planets with lower gravity than Earth, brochures might advertise the weight loss benefits of a visit!

To capture factual data, Belinda created an Excel spreadsheet and placed it on a shared drive, into which the students entered all of their planetary figures; resulting in a

[27] The district used Jamie McKenzie's model, which can be found at http://questioning.org/rcycle.html

[28] 5. Use technology for research, problem solving and decision-making.

5.1 Use technology to locate, evaluate, collect, and organize information from a variety of sources.

[29] In 2002, Pluto was still accepted as a planet, rather than a dwarf planet.

collection of data for further class work in mathematics. Also using these planetary statistics, we created three scale models of the solar system. The first, more approximate representation using assorted produce; the next, more exact one, using measuring tapes and colored, paper planets in the hallway outside the classroom; and the last outdoors on a considerably larger scale, which extended off school grounds and down an alley. In these tasks we encountered issues with measurement as the class needed to convert distances to a single, uniform scale (often from standard to metric values).

During this time, I used the Starry Night™ software, loaded on my iBook, to informally demonstrate animated scale models of the solar system. We were also using this software to model lunar phases and seasons to supplement hands-on lessons with physical models during this time. These Starry Night™ experiences were not structured lessons; rather I had it running often on my computer, and I encouraged students to experiment with it. Soon I realized that some students were very interested in this software, so I loaded it onto Jupiter, the computer attached to the television monitor in the front corner of the room. Other web sites were used in order to model Earth's seasons, lunar phases, and solar system scale and motion.[30]

Project 2: Space exploration programs

We began this two-part lesson as a class project, with students working in pairs. For Part One, using a list of space exploration programs and events (see Appendix D), and a separate list of dates, the student pairs used the computers to research the programs and events and match them to the correct dates, and then placed them on a timeline they

[30] The Earth/Moon System: http://jove.geol.niu.edu/faculty/stoddard/JAVA/moonphase.html
Length of Day & Night: http://www.cs.sbcc.net/%7Ephysics/flash/LengthofDay.swf
Solar System Orbits: http://www.solstation.com/orbits/solarsys.htm

constructed out of adding machine tape. Also, the students were given a list of events related to the invention and use of the telescope, already matched to their dates, and directed to place these on their timelines. This was an exercise in mathematics of scale as well, as students had to determine an appropriate length of tape, in addition to a scale which would fit their data well. These tapes were then posted on the wall of the hall outside the classroom, so that other classes could see their work.

For Part Two, student groups were randomly assigned one particular space exploration program to research further from the list in Part One. Students were given a list of guiding questions for research, and then directed to prepare a PowerPoint™ presentation of their data. The programs chosen were a mix of manned and unmanned missions: Apollo, Challenger, Gemini, Mars Pathfinder, Mir, Skylab, and Voyager. These PowerPoints were saved on a shared drive, and presented to their classmates in the computer lab, where an LCD projector was connected to one of the computers.

Project 3: Independent research

At the beginning of the year, students were told that they would have an opportunity to do an independent research project, about a topic of their choice in the areas of astronomy and space exploration. They were asked to keep track of questions and ideas they might have throughout, so that they could choose something that intrigued them. In early November, we told the students that the time had come to finalize a topic. The end product was to be something that could be presented in a class Science Fair, which would be attended by all of the other classes at Bayview. In addition, a community presentation would be planned so that parents and other family members could see their work. The end product did not have to be technology-based, therefore it could be a model, diorama, poster, or a PowerPoint™ or video presentation. The basic requirements were some sort of demonstration, a visual aide, and a short paper. A list of their choices, which were quite wide-ranging, can be found in Table 6-2 later in this chapter.

As I mentioned in the previous chapter, Belinda was comfortable leaving the field wide open for the students; secure in the knowledge that they would find useful information about just about any topic on the Web. She and the class were no longer limited by the materials which could be found in the school library or in Belinda's limited resources. Technology provided an advanced level of openness for the learning system of the Bayview classroom. Ideas that emerged from the students could be explored easily, at times with assistance provided by teacher-created structures.

Project 4: An exceptional undertaking, or 'Cataloging the Solar System'

Though this was not an assignment in the class, it is important to mention a particular project undertaken by three boys: Ethan, Gabriel, and Luke. These three boys decided in October that they wanted to research *all* of the planets and moons in the solar system, and put them together in the "greatest PowerPoint™ of all time!" They worked on this project, in addition to all of their regular work, through the entire school year. In December, they officially unveiled the first volume of their PowerPoint™, which included all of the nine planets. By February, they had catalogued about 75% of the known solar system moons, and included it in Volume Two. By the end of the year, they had included all moons, and a good percentage of the asteroids and comets. These three boys did most of the work, but they also enlisted other students in the class as researchers. As Belinda stated, "it was good that these students found a shared passion at school, but also this is really developing into a collaboration between the students [and their researchers]" (2/23/03 interview).

How Students Interacted with the Computers

Computers, Books and other materials

For the most part, students preferred using the computer to find information. As Belinda noted, "it's interesting that when we do start talking about research, I notice that the students automatically go to the computers first – but I usually require them to look in a book resource – just so they can kind of double check the information" (8/21/02 interview). Belinda still valued and trusted books, while students seemed to trust the computers more. In the interviews I conducted with the students towards the end of the research project, I asked them if they preferred using books or computers for research. Also, I asked them if they thought they could have done their research without the computers. Most stated that they would rather use a computer than a book, but for a variety of reasons. For example, Brooke cited ease of information retrieval; "I'd rather learn with them [computers], because all you have to do is write what you want to research and stuff and then it will give you a lot of information" (December 2002 interview). Luke referred to the limited information available in the Bayview library; "I don't think you could have found most of the things – the info. on the ISS – that is either way too new or way too old – I don't think you'd be able to find it here [in the Bayview library]" (December 2002 interview). Not everyone was convinced of the value of computer use in school, however. Emily stated "they're [computers] kind of like my last resource. I usually go and ask people first, then I go to books, then I might see what my friends know, then I go to computers." However, when I probed more, Emily said "well, I think that, maybe, because I use (them) so much at home that I don't want to use them at school, because I don't want to use the same thing over and over and over again" (December 2002 interview). Perhaps Emily prefers the social context of learning in school, and sees the computer as a more solitary pursuit.

Solo, Pair & Trio

Due to the limited number of computers in the classroom, for the most part students worked in pairs and trios on the computers. This was not an issue for most students, as they had been working together for most of their time in school. In the beginning of the year, at times Belinda and I had to remind students to share the work, and/or take turns as appropriate. But, for the most part students moved fluidly from solo, to pair, to trio as needed. Also, this class had the luxury of often being able to overflow to the 'stage' area of the library, and the computer lab, if more computers were needed. The ease of access to computers provided a structure that was fluid enough to allow for self-organization; students and teacher adapted from solo, to pair to trio as the task demanded.

Having a computer for every student might very well have stifled this fluid nature of relationships in the classroom, resulting in social isolation at worst; or lessening of neighbor interaction at least. Belinda did say that:

> There are times when I wish I had a computer for everybody, of course – especially when one or two are out for repair. But then it's nice for them to learn how to work together and to team with the computers too. To take turns sharing and watching each other maneuver around, I think that's valuable also, at this point (10/15/02 interview).

When students were asked about their preference in working alone or in pairs/trios on the computer, I found that their answers were at times task dependent. For example, Luke said, "it depends on what kind of thing it is. If it's PowerPoint™, I like to work with people. But with writing, I like to work alone" (December 2002 interview). Some students, such as Karen, preferred to have their own computer, "...so you don't have to share, because maybe the other person doesn't know as much as you and you kind of have to walk them through"

(December 2002 interview). But others, such as Daniel, preferred to work with a partner, "because I'm new to computers. I don't know how to type something in like 'dot com,' and I don't know how to do Google™" (December 2002 interview). Through this line of questioning, I was able to discern that many students didn't see working in partners as a combination of resources, but rather as a division of labor which may allow a project to be completed more quickly. To them, having a partner often meant that each could tackle a separate piece of a project. For example, Kirsten stated that "when you're by yourself, you're independent – you're working separately – but when you're with a partner it's easier, because it's going twice as fast as it normally would" (January 2003 interview). Perhaps some tasks could be broken down into component parts, divided up between students to accomplish, and then joined together in a coherent whole. This did happen with some groups when they were working on computer research projects. This could be compared to research using books, in which students divided up the sources to be read as well.

A notable practice emerged amongst many of the students when working together on the computer. One day when I was in the classroom in early October, I noticed two female students, Robin and Tara, working together on a computer. Nothing noteworthy there, until I looked more closely. I found that Robin was typing on the keyboard as Tara was maneuvering the mouse. They were doing this quite fluidly as they traveled through various web pages, searching for information. As I watched, they continued to do this; it was not a momentary event. They were talking during their work, but very seldom did one direct the other to do something with the mouse or keyboard. After grabbing my camera and recording this, I asked the girls if they often worked that way. They looked at me as if I were asking them how they breathed! They appeared to think that this practice was not out of the ordinary. In fact, as I observed other students throughout my time in the classroom, I found others doing the same thing.

I spoke with Belinda about this, and she also voiced surprise at such a practice. When we did one of our formal interviews in November, I asked her how students were doing working in pairs on the computers. Belinda believed they had figured out a way for both students to participate:

> Earlier, I think it was more 'you do this and I'll do this,' because they weren't quite sure of each other yet. But now there's literally going to be one typing and the other mousing [*sic*]. I have seen that more than once, and it just makes me think 'I could never do that.' I couldn't! They just seem to meld when they're working (11/26/02 interview).

However, not too long after that, I was working with Emily, who was having trouble getting her paper to print. As I was working with her on one of the computers, I found that I was typing while she was 'mousing.' So, I too had learned how to work in concert with someone else on the computer! As I reflected on this, I realized that very seldom had I ever needed to work *with* someone on a single computer; I have almost always worked alone. Perhaps these children are able to do this so fluidly precisely because they are often working together.

Working together on the computers, and in close physical proximity to other pairs working on their computer, allowed for a great deal of conversation between and among students. This meant that students were usually quite aware of information being found by others, but could also provide for distractions.

Students Searching for Information

As I mentioned previously, students usually went straight to Google™ when looking for information. However, searching accurately and efficiently was difficult for them. Often, students chose terms which were too broad. For example, when a student typed in 'Venus' while looking for information about the planet Venus, sites relating to Venus the goddess, the Venus di Milo statue, and the Venus ladies shaver would result. As Alicia said, "you have to be really specific with what you ask or else it will come up with something that you didn't even want" (December 2002 interview). Most searches, even if more narrowly phrased, resulted in hundreds or thousands of hits; a bewildering array of choices to weed through and evaluate. Students usually would click on the first one on the list, without looking at the short synopsis provided to see if it related to their searched term in the way they wished. Then, the practice of randomly clicking on hotlinks would begin. Students needed to be taught to filter and critically engage with information, as "the Internet is a fundamental contributor to an ever-growing information glut that requires the ability to discriminate between fact and fiction, waste and value, that all too few possess" (Gordon, 2000, p. 3).

A few students learned how to search more effectively. For example, Tara learned how to do the more refined 'advanced search' from Chloe when they were working together. That taught Tara how to exclude some terms from her search for information about Mercury. Students often learned a lot from their peers as they began to lean more and more on each other, rather than asking Belinda and me for help immediately. They shared search tips, and good websites.

Once students had learned how to save Favorites on Internet Explorer, many more sites were added to the Space folders I had created on each machine. However, they rarely looked to see if their 'new site' was already in the folder, so periodically I would go into the folders and eliminate duplicates. In this instance, I acted as an enabling constraint; creating and fine-tuning the Favorites folders for ease of navigation, and also making information easier to access for the students. Sometimes I also observed that students would completely ignore the Favorites folder and choose to start a new search with Google themselves. When I asked a student (Brooke) why she was doing that, she said that she only looked in the Favorites folders on computers she worked on most often. Then, she was looking for links she had added herself. She wasn't interested in links to pages others had found. Though I didn't pursue this line of questioning further, I suspect that the communal potential of the Favorites folder was lost on some students.[31] Some of that may have been due to Favorites not being given descriptive titles, but I believe that some students enjoyed the process of typing in their question terms and getting the computer to find the answers. Also, as many students exhibited difficulty in reading for information and scanning for good sites on a search results page, it may have been that they had equal difficulty in scanning through a long Favorites list looking for appropriate links.

Belinda and I often worked with students to help them to read Web sites for information. We also asked the school Media Specialist, Seth Jacobs, to support the skill of reading for information in his regular computer lab lessons. It seemed that in some ways, the students thought of the computer as a sentient being; something that "knew" things, which should just tell you the answer to your question.[32] A common complaint from the students was that the computer gave them too much information. For example, Cory said, "sometimes computers have pages and pages of stuff that you don't need to know and then

[31] Interestingly, Brent Davis, in a talk he gave at UBC in March 2006, brought up the possibility of Favorites folders acting as a communal memory of a classroom learning system.
[32] For example, Alicia spoke of her frustration with computers by saying, "computers don't *know* everything" (December 2002 interview, emphasis added).

right in the middle they have what you do need to know" (December 2002 interview). Students were often too impatient to read through a whole page, or even half of a page, to find what they wanted. Also, if the needed information was not found immediately, "students often got lost as they just kept clicking more and more through websites. They would forget what they were looking for, and where they had started. Just click, click, click – it was hard to maintain focus" (Belinda interview 10/15/02). As Belinda stated later, a skilled technology student needs to know:

> when they are in an area that is not helping them answer their question and be able to look at that and say 'okay, this is not helping me. I'm going to exit out of this and go find something else' (2/23/03 interview).

I asked Belinda to contrast the students' practice of searching for information with what she had seen with previous students when using books and other printed matter for research. She stated that if students had been using something such as an encyclopedia (hard copy), which laid information all out for them, it would have been easier. However, "they would not have found the depth of information that they need to have for a serious research project" (11/26/02 interview). Being required to *synthesize* information, often from a variety of sites, led to deeper understanding of the material, rather than regurgitating information from an encyclopedia. The more open nature of the computer data sources, as compared to the more linear, reductionist, and hierarchical organization of an encyclopedia, provided for a potentially deep interaction between the students and the material. The Web did not always provide information in a neat and tidy form, but in order to answer their questions, the students had to critically engage with the material; to sort the wheat from the chaff.[33]

---

[33] Having worked with adult students when looking for information on a computer, I know that search skills take some time to develop. Each teacher at each grade level would have to work with students to develop this skill. This may be a structure that must be provided, in order to encourage the emergence of this skill.

Interestingly, students had a tendency to trust the information contained in websites completely. To them, if it was on the screen, it must be true. We had to teach them to check for confirmation of data, and to examine characteristics of a site to see if it was providing accurate information. However, though a published encyclopedia would generally be more trustworthy, perhaps this was a necessary, and beneficial, trade-off.

Belinda also talked about how some students just persevered, and kept weeding through information on the Web until they found what they needed. Because of the wide-open nature of the Web, students often found pages that were written at a technical or very high reading level. Some students took these pages on as a worthwhile opportunity to work with primary, non-predigested data; which often led them to further questions. As Belinda commented, this diversity of material was good for developing reading strategies, as "there are so many organizational setups on the Internet – just different websites are organized differently" (8/21/02 interview). However, this could be challenging for some students, as "they came across a lot of difficult facts and websites that were difficult for them to understand…if they didn't know the basics... but once they found some sites with basic information…then I think it was easier" (11/26/02 interview). Alas, the Internet is not organized by reading ability; though some sites such as Windows to the Universe[34] offer pages at different ability and content levels.

The Role of the Computer in the Classroom

As time went by, the computers became increasingly part of the natural environment of the classroom. At the beginning of the year, Belinda began a job rotation for students to take care of everyday maintenance and tidying tasks. One of these responsibilities was making sure the computers were cleaned and turned on in the morning, and turned off at the

[34] Windows to the Universe can be found at: http://www.windows.ucar.edu/

end of the day. They were taken care of just as any other equipment in the classroom would be. As Belinda stated, over the previous years of the Gates grant:

> that was a big mind shift for me and the students – that this is just part of our room. It is just like your desk or anything else. You use it. It is part of the furniture. It has its place and its usage and you use it as you need it (2/23/03 interview).

However, it had been a progression over three years to get to this level of regular, natural, and seamless integration into the classroom environment. It usually does take a few years for teachers to integrate technology into instruction in meaningful ways (Sandholtz & Ringstaff, 1996). The emergent nature of this process was described by Belinda this way:

> It has been quite a change. I mean, just starting with getting the computers in there and figuring out what the heck am I going to do with these computers, to now, you know, jumping forward all the way up to working these great projects and feeling like it is part of what I actually do in my classroom every day. (Pauses) You know, so there were those kind of little intermediate steps of just kind of taking on something small with the writing and feeling like "Okay. I can handle that. We can do a small project here or there." But it was kind of like a separate time—"Okay. It is computer time." It was like "Okay. Let's schedule that into the day and figure it out and when we're not on the computers, we're just not on the computers." Whereas now there might be one or two kids on the computers working on a project—throughout the day, there are always kids just kind of going over there and working on things. So it just seems really natural, like it is just part of the regular flow of the day (2/23/03 interview).

Over time, the students also took more ownership of the computers. In early October, Belinda and I began to notice space-themed wallpapers appearing on the machines. While observing the students, I saw that they had learned a shortcut to make any picture they found on a webpage into the computer's wallpaper. As students found photos they liked, they placed them in the background, often many different times while on the computer. In our October interview, I asked Belinda about his practice. She said that students enjoyed this aspect of control over their learning environment, and that "some teachers are – they don't allow their kids to change the wallpaper and stuff, and it's like 'those aren't *my* computers.' There are some basic rules, how you take care of them, but they are *ours*" (10/15/02 interview).

Time and ease of access were crucial factors in the integration of the computers into the regular daily life of the classroom system. First, Belinda needed time with them to figure out what they could do for her students. This initially required that they be treated as a new, separate tool; one that was quite different from regular equipment in the classroom; at times needing very special care to function. Over time as Belinda found more and more good curriculum resources for her students, and as she became increasingly adept at dealing with technical issues, she began to use the computers even more. With increased use came more comfort for her and her students; and vice versa.

Problems with the Computers

Even though there were eight desktop computers in the Bayview classroom, it was a rare event when all of them were functioning and available. When the children first named the computers, it was no coincidence that one was named the 'Black Hole.' This was the machine that was continually acting up and crashing unexpectedly; out of service far more than functional. Early in September, Belinda placed a work order with district technical support for the Black Hole. In late September, one of the district computer technicians removed it from the classroom for service. It was returned, in working order, in early December, after an absence of nine weeks. 'Jupiter' also was continually acting up; with the mouse ceasing to function, and the monitor going blank unexpectedly. 'Ursa Major' consistently crashed if a user went more than three links through a search page; ultimately resulting in its removal for six weeks. The monitor for 'Polaris' often blinked on and off, but would stop for a while if hit on the side. These, and other problems with printers, occurred throughout the year. Belinda hesitated to report problems to district personnel as that usually resulted in a computer being gone for a long time, with no replacement, as the technology support personnel were stretched very thin.

However, Belinda reported that this year was not as bad as her two previous years with the Gates Grant computers. In Year One the school Internet connection was unreliable, resulting in it being down more than it was up. In this, Year Three of the grant, the Internet was usually functioning well. When I asked Belinda if she found herself planning two lessons, one with and one without the computers, she said she really didn't do that anymore; though she had done so in her first year with them. As she saw technology as a support for her lessons, and not the focus, it was not a big deal if they were not working. She and her students would merely adjust the lesson to a more hands-on focus. This was a good example of a high tolerance for the emergent nature of teaching integrated with technology.

Also, Belinda had become more proficient at repairing her own equipment. She no longer called for support for simple things. She was able to check for proper connections, and knew how to force a restart on a faulty machine. With my encouragement, she also had switched a good monitor from a malfunctioning computer to a computer with a faulty monitor. Being in close proximity to Seth Jacobs (the Media Specialist) provided an advantage with technology support as well. For example, one day a mouse was acting up. Normally, protocol demanded that district support staff be contacted about any equipment replacement. However, Seth had been saving functional mice from older, and malfunctioning, computers. Belinda was able to go across the hall with the culprit and get a new mouse within minutes. In another example of distributed power in the classroom, most students were also unafraid to jump in to try to fix things, and some were quite proficient.[35] For instance, Luke was the designated computer repair person at home (December 2002 interview) and also often acted in that role at school. Most students reported in their interviews that they felt comfortable trying to fix a balky computer before asking for help. One exception was Kirsten, who said that she "didn't really want to fix them, because I might mess it up more. I normally just go get a teacher and then get a book. If I ask another kid, they might make it worse" (December 2002 interview).

One obstacle we encountered was the limited software on the classroom computers, and the restrictions placed upon adding software. One morning in early September, a student arrived and told the class that she had been listening to 'Star Date' on the local NPR radio station on the way to school. Star Date is a three-minute syndicated spot from the University of Texas which explores astronomy topics, often relating to that particular date. Many students had not heard about it before, so we decided to have a look at the companion web site (http://stardate.org/). On their page, there is a link so that you can listen to each day's program, using RealPlayer™ audio software. The students, who were often magnetically attracted to audio and video links on web pages, wanted to listen. However, the classroom computers were not loaded with RealPlayer™; a free, downloaded program. I assured them that I would get the software downloaded while they worked on other projects, so that we

[35] Though the district Technology Plan specifically stated that students should be proficient at troubleshooting minor issues with computers, many teachers and technology support staff discouraged this practice.

could listen later in the day. Thus began the saga of attempting to alter a school district computer.

Working on 'Jupiter,' I clicked on the link to download the appropriate version of RealPlayer™ for our PCs. After asking Belinda where the program should be installed, as I was a Mac person and wasn't fully conversant in all of the drives for the computer and school networks; I downloaded the software. It appeared to install smoothly, but after restarting the computer as directed, I could not get the application to start, though it did appear in the Applications folder. At first I assumed it was my error, so I asked Luke (who was hovering, waiting to be asked to help) to give it a go. We had no luck, nor did Belinda. At this point I enlisted the aid of Seth Jacobs, who also failed to get the program to work on 'Jupiter,' or any other computer in the classroom, or in the computer lab. We gave up for the day.

The next morning, I brought in my radio, so that we could listen to Star Date in this manner (it aired during settling-in time in the mornings). Over the next few weeks, Seth and I attempted to contact the district technology support staff via telephone and e-mail, but with no response to our messages. We both kept tinkering with the issue; experimenting with different computers, both student and faculty, as we were beginning to suspect this might be a security or firewall issue. Meanwhile, Belinda had found the schedule for live online chats with NASA astronauts and engineers, which was a technology-rich activity we had incorporated into our plans for the space exploration portion of the project. These chats also required RealPlayer™. Believing that we would resolve this issue successfully, Belinda signed up to do the chats, and told the students about them. The students began to prepare questions to ask in the chat.

However, Seth Jacobs finally got through to the district supervisor for technology, who told him that no new software could be loaded on any machines without going through an approval process. Also, all approved software had to be then installed on **every machine** in the district, and only by the district staff. Seth, who had not been aware of this policy, despite his role as technology support person for Bayview, asked how he might begin that request process. He was told that the request process could only begin in June for the following school year! We were out of luck. When we told the students about this restriction, Ethan said, "gee, that shouldn't be so hard; I installed that on my computer at home last night!" So, we had to abandon the NASA Live Astronaut chat, one of our components of the space exploration unit.

Technology and the Topic as Student Motivators

As I mentioned earlier, the students were highly motivated to work with technology, and to do projects in the area of astronomy and space exploration. In the realm of technology, a simple constellation web page that filled in the picture for a student after completing the dot-to-dot drawing was more fun than doing a typical worksheet. On a deeper level, having virtually unlimited information literally at your fingertips; knowing that almost any question could be explored, was very motivating for the students. Students were no longer restricted to the materials that Belinda could personally provide; but rather the world opened up for them. As Belinda stated, technology "personalized the education for them. They were opened up just to ask" (8/21/02 interview). Also, students could make the computer work for them and their style of learning. "Linear students could use it linearly, and those who were not could approach it in a more holistic, emergent style" (2/23/03 interview). Fundamentally, using technology was "way more student-centered. It's more about what they are interested in and they feel that responsibility and that they can have some say in how they are going to be working" (8/21/02 interview).

Though Belinda used the phrase 'student-centered' in the previous passage, the customary dichotomy between 'teacher-centered' and 'student-centered' is not of much use when thinking in terms of a collective and complex system. Such a collective classroom as Bayview may be described in terms of decentralized control, with neither teacher nor student existing at the center.

The topics of astronomy and space exploration were of high interest to the students. Many had been influenced by these topics as presented in popular culture. This was a motivator, but we also needed to deal with the alternate conceptions that can result from this exposure. For example, many students were under the impression that the Space Shuttle could, and often did, travel to the Moon; though of course its range extends only to low Earth orbit. This inaccurate understanding was reinforced by graphics, such as that seen in Figure 6-5, found in Microsoft Clip Art, when entering the search term "Moon." The Space Shuttle was also seen as the iconic space vehicle; its image often appearing in presentations about other programs such as Mercury, or Apollo. However, as these students were relatively young, many had not yet formed some of the more common alternate conceptions found in adults. For example, on a lunar phase pre-assessment worksheet, when asked why the Moon appeared to change shape, some students really had no idea, and recorded that as their answer. Only five students (of 24) attributed the cause to the shadow of the Earth, while two wrote that it was due to the different amount of light on the Moon. For many students, this was their first exposure to astronomy at school, or in any context.

Figure 6-5. Clip Art resulting from a search for "Moon"

Preparing a PowerPoint™ Presentation for an Authentic Audience

As any sleepy professional conference attendee knows, PowerPoint™ presentations do not automatically provide for a deep, rich synthesis of information. They run the risk of being simply lists of data, or text copied verbatim from websites, just as the written report does. However, a well-constructed PowerPoint™, especially created for an authentic audience, can be a powerful learning tool. Students are motivated to do their best research for a polished product that will be presented to their peers; school community members such as students, teachers, and administrators; and family members. The Bayview students often talked about how they wanted their projects to be good as they would also be posted on the class website.

Before we began the Space Exploration Program research project, Belinda led a discussion with the students about their research process and final product, which would be a PowerPoint™ presentation; the first of the year. At this time, Belinda provided a list of guiding questions to help the students with their research. After most of the student groups had completed their research, and were ready to move on to making their PowerPoint™, Belinda then led another discussion in which she asked each table group to generate a list of elements of an effective PowerPoint™. Again, Belinda did not want to overly direct this process, but rather help the students to determine guiding parameters themselves. In order to assist the students, Belinda had them use the Six Traits of Writing, employed by the school district,[36] as a framework. Students had been working with these Six Traits in various ways throughout their years in the district, so they were familiar with them. In this example, the Six Traits served as an enabling constraint. They represented a structure for writing already known to the students (and teacher) which helped the students to create appropriate guidelines for another form of written representation, a PowerPoint™. The student list, which Belinda recorded on chart paper, was actually quite inclusive:

1) Ideas & Content

- Clear, focused, and doesn't drift off topic
- Real pictures, that relate to the topic
- True facts
- Bibliography
- Include main ideas and important details
- Shares insight (tells what you think)
- Addresses the audience (them, Ms. Knudson, & me)
- Makes sense
- Has enough information
- Don't copy materials
- Not same thing over and over

2) Organization

- Stick to the topic
- Order your information so that it goes together
- Right amount of information
- Transitions should lead you from one slide to the next: flow
- Readable font and size
- Beginning, middle and end
- Makes sense & goes together

3) Voice

- Loud enough
- Clear
- Generate interest through enthusiasm
- Talk directly to the audience
- Lively (not flat) voice

---

[36] Information about the Six Traits can be found at http://www.nwrel.org/assessment/about.php?odelay=1&d=1

- Be honest in your opinion

4) Word choice

- Easy to understand
- Explain new or difficult words
- Limit number of words per slide
- Specific, to the point
- Make a picture in your mind, and support with real pictures

5) Sentence fluency (flow)

- Start sentences (bullets) in different ways
- Use bullets and phrases
- Complete (don't leave out information)

6) Conventions (COPS)

- Capitalization
- Organization
- Punctuation
- Spelling

❖ General things

- Animation and sound should tie in to content, and don't overdo
- Students can judge this without teacher restrictions

This list was then typed up by the class secretaries, and passed out to the students on paper for reference. When either Belinda or I had checked that their research was complete, then the students were cleared to begin their PowerPoint™ construction.

Most students had prior experience with making PowerPoint™ presentations, so they needed little direct instruction in how to create one. Belinda consciously chose this medium for information presentation because she wanted students to be able to focus on the content, rather than the delivery (9/10/02 interview). Students made these presentations for their classroom peers, while the next assignment would be for a broader audience. This work for an audience of their classmates took on more importance. Students were not merely writing a report for a teacher who already knew their information, and would merely check off that now students (hopefully) knew it as well. Students were learning with a purpose, that of informing their peers. As Belinda phrased it, students needed to remember that "someone's actually going to be listening to what I'm saying, so I had better make sense, and I had better know what I'm talking about" (9/10/02 interview). However, in actuality, when the students were in the audience, hopefully to act as critical peers, few were willing to question the presenters, let alone challenge any of their data. An interesting question is for whom would students of this age produce their best work? For their peers? Or for the authority figure of the teacher?

This first wave of presentations went pretty well, though the level and amount of actual content varied widely. Belinda said that she "thought they [students] learned a lot and they did really well with their group process skills – it was successful" (11/26/02 interview). Most students resisted the temptation to overuse animations, sounds, etc. Many still had problems with putting too much text on one slide. Others still used images of the Space Shuttle, even when they were presenting data about the Gemini or Apollo programs. Some students read their slides to the class, rather than using the slides as support for their presentation. During the presentations, the students in the audience used a structured worksheet to take notes about each exploration program; and to give feedback to the presenters. Belinda then checked these for a participation mark before passing them on to the presenters. This worksheet also represented an enabling constraint, created by Belinda to help students pay attention to presenters and supply feedback, and to scaffold audience members in taking effective notes.

The Independent Research Projects

In past years, Belinda had done a science fair/celebration with her classes. This year was to be no exception. Presentation to the broader school community served "to solidify what they [students] actually did learn – more than 'Okay, I did this big project and here's all my stuff.' So, what does that really mean – it gets into that reflection" (Belinda 8/21/02 interview). In order to truly make this a valuable experience for the students, Belinda and I decided that the topic for this project would be completely up to each student; as long as it related in some way to astronomy and space exploration. We told the students about this project early in the year, so that they could be thinking about what they wanted to know more about during their other research. Nevertheless, some students had difficulty in choosing, and sticking with a topic.[37] The student choice of topic was varied, as can be seen in Table 6-2; with some expected ideas, such as black holes, but also some rarer choices, such as astrophysical jets.

[37] I don't believe this was due to the limitless range of possible research topics. I have seen the same indecision in students working with only printed resources.

Student Name	Project
Mike	Werner von Braun
Chloe	ISS
Andy	Worm holes
Kendra	Sally Ride
Rebecca	Earth
Alicia	Animals in space
Emily	Life of a comet
Brooke	Stars
Karen	Black holes
Kirsten	Constellations
Robin	Making a rocket
Tara	Sun
Jack	Atomic structure (making physical model)
Gabriel	Kuiper Belt
Scott	Astrophysical jets
Sean	Building rockets
Cory	Black holes
Luke	Saturn
Ethan	Black holes
Bob	V2 rockets
David	Charon
Frank	Crop circles
Daniel	UFOs
Abby	Moon

Table 6-2. Student Independent Research Topics

The basic requirements for the project were a short paper, a demonstration of some kind, and a visual aide. The students were not required to incorporate a technology component per se, but many did so. All at least used the computers, in conjunction with printed materials, to do their research and produce their final products.

The faith that resources would exist for just about any topic made it so that Belinda and I could allow students to pursue any topic that interested them. For Belinda, this was an incredibly opening experience, after being restricted to her own, or library resources. Before receiving her computers, Belinda had to "stay in the box, because that is what we have – so this is what we are doing. [Having the computers] has opened a lot of doors for me" (2/23/03

Belinda interview). This freedom to explore a broad range of ideas could be a little overwhelming, but also enjoyable; for the students, and for Belinda.

The students presented their independent research projects just after lunch on the Thursday before the Winter Holiday began. The event took place for the most part in the classroom, but with quite a few displays out in the hall and in the library. The students made invitations with Publisher for their families and other classrooms and staff at Bayview. Throughout the afternoon, parents circulated through the classroom, as did the building principal, and all of the other classes (and teachers). In addition to their individual projects, the students placed their previous Space Exploration PowerPoints on the various computers around the room. This was a festive occasion, with holiday music playing on the class boombox, and sparkling grape juice and cookies for the attendees.

Most students used a traditional tri-fold poster display, with photos, drawings, and other materials attached. Models were constructed out of clay, Styrofoam, cardboard, Legos™, etc. Some students employed the computers for PowerPoint™ shows, appropriate Web pages, or animations for their displays. One student, Mike, came dressed in character as Werner von Braun, and would do an autobiographical performance on demand! Throughout the afternoon, I circulated among the students with my videocamera, asking them to show me their projects and reflect on the experience. Students universally said they would like to do a project like this again; especially as they were able to research any topic they chose. They also thought it was good for them to prepare for the 'real audience' of other classes and their families.

How Technology Enabled the Work of the Bayview Classroom

Sharing Work in a Polished Form

Using the computers to make planet travel brochures with Publisher, and Space Exploration PowerPoints, allowed the students to share a professional, polished product, as opposed to a handwritten paper or poster. When I asked students in their interviews if they thought we could have done the projects without computers, many spoke of how their work looked better when done on the computer. As Abby said, "I could have done it without the computers, but the writing looks neater and I just like having my stuff look neat" (December interview). Also, Rebecca preferred making a PowerPoint™ as opposed to a written report, as there was a visual component, so "you can kind of see it and stuff" (December 2002 interview).

The issue of word processing as compared to handwriting was one that Belinda and I discussed often. Handwriting skills are still in the official curriculum of the Bayview school district, though students are not tested directly on these. Some of her students had been trained in previous grades to recopy their work in their best handwriting and had not been allowed to use the computer to publish final drafts. However, using Word or Publisher to write a document allows students to revise their work more easily, with a neater finished product. The traditional ways of teaching the writing process are adapting and changing to technology (McQuinn & Roach, 1998). Also, in their future work in higher grades, students are expected to turn in papers produced on a computer. Unfortunately, the statewide writing assessment is still conducted completely by hand on paper. Therefore, Belinda still must work with students on writing legibly and coherently without a computer.

The Unending Nature of Research

A research paper or a poster has a finite end when it is turned in to the teacher. It is finished and will no longer be changed. However, a PowerPoint™ "can keep changing – it's not like a paper that you turn in and it's gone" (11/26/02 Belinda interview). This was most apparent in the 'Cataloging of the Solar System' project undertaken by a small group of students in parallel to the regular work of the classroom. However, using the computers to access almost unlimited information about topics students were excited about meant that at some point Belinda had to decide when a class project was over and move on. That did not mean that students could not continue with their research on their own time, which many did. Also, PowerPoint™ files were saved in the students' personal folders on the student drive for the school. This allowed them to revisit them and tweak as they wished, which some students continued to do through the year. In addition to being placed on the class web site for the year, Belinda kept electronic versions of the presentations for future students to see. This was more difficult to do with the paper reports of the past, which were customarily returned to students.

The 'Cataloging of the Solar System' PowerPoint™ project had its beginnings in the first planet travel brochure assignment. Ethan, Gabriel, and Luke were three bright, computer-savvy students with a very high interest in all things 'space.' These were the three students who showed such an interest in my Starry Night™ software; so much so that I loaded it on 'Jupiter' at the front of the room so they could experiment with it any time they wished.[38] At some point, they decided to make the 'ultimate PowerPoint™' about our solar system. They began by gathering information about the planets, and presented this first volume to the class in December at the Science Fair. This was a pretty sophisticated

[38] Miraculously, this installation of software worked flawlessly as it was not downloaded, but rather came from a CD.

presentation, with a high level of information. After the Winter Holiday, class study of space was over, and Belinda had moved on to a social studies unit about exploration. I had, for the most part, concluded my research, though I conducted some of my student interviews in January. However, these self-described 'Space Nuts' continued their research on their own time. In order to gather even more data, they enlisted the help of student researchers. By the time of my February visit to the classroom, the boys were ready to show me a preview of 'Planetary Statistics: Volume 2;' and by the end of the year they had produced two additional volumes, which were shared with the class as well. For all we know, those boys may well have continued this project through the summer, as they said they wished to do. It is significant that this was not a planned assignment; rather it emerged out of classroom experience and took on a life of its own. Neither Belinda nor I ever considered stopping this project. On the contrary, Belinda encouraged the boys and their researchers to continue, so long as the project didn't interfere with their other assignments. My continued visits throughout the spring were not complete without a viewing of the latest installment of 'Planetary Statistics!'

By encouraging, rather than stifling this project, Belinda redistributed some of her power in the classroom, while still being in control; which was one of the things she mentioned in our initial interview. She voiced a desire for her students to learn about things that excited them, and to learn things she did not know herself. This was empowering to students in general, but in particular for Ethan, Gabriel, and Luke. As Belinda stated, that experience:

> was beyond rich. It was very motivating for them. And socially, too – for those three to make that connection – it was very, very important for them to make that

connection. So it had lots of different layers of good learning happening (2/23/03 interview).

Concluding thoughts

The technology tools in Belinda's classroom extended and broadened the experience of the learning community. Students engaged with data from a wide variety of sources, then evaluated, organized, synthesized, and shared their findings with an authentic audience. Belinda consciously distributed power to her students, and shared their enthusiasm in learning about astronomy. In the next chapter, I discuss how the Bayview classroom as a complex system engaged with technology tools.

Chapter Seven: The Bayview Classroom as a Complex Learning System

Belinda's classroom, like most classrooms, already existed as a complex learning environment before the introduction of the Gates Grant computers. Its complex nature can be considered as a condition or structure which nurtured the development of technology as an imaginative extension of the learning environment.

Complexity in General Terms

In Chapter Three, I related the characteristics of complex systems in general, and also as they relate to educational contexts. The Bayview classroom was **adaptive**, evolving and unfolding over time, in that members adapted to the world they co-created, and as the members changed, so did the classroom collective. For example, individual research projects helped to guide the learning of the whole class, as ideas and data emerged into the community. These **emergent** components then introduced new levels of complexity, as the community moved in new directions. Tolerance for the emergent nature of her classroom allowed Belinda to deal with the technical issues that accompanied the new computers and the school network, and to persevere.

The Bayview classroom system can also be described as **holistic**, in that order emerged as a result of the interactions of all components. Belinda, as teacher, occupied a special position in the Bayview classroom learning system; that of an enabling constraint, which I shall discuss more fully below. The class could also be considered to be **non-linear** in that it was more than an agglomeration of its parts, and the sequence of classroom activities was not and could not be determined in advance. The behavior of the entire classroom community could not be understood by examining the behavior of individual members such as the students or Belinda. Also, if you were to examine other components, such as curriculum, or technology tools, those alone would not determine the actions of the whole classroom.

The Bayview classroom would surely be defined as **open**, in that the various agents in the system were always bringing in new ideas and energy. Technological tools provided for this openness, bringing in new information and perspectives from a wide range of sources throughout the year. However, Belinda and I also needed to provide an environment that nurtured these emergent practices. To that end, access and ease of use for the computers was maintained. In addition, all members of the community, including Belinda, the students, me, and other more peripheral members such as Seth Jacobs (the Library Media Specialist), parent volunteers, etc., brought in diverse ideas, concepts, and representations.

There were a number of instances where I observed different forms of **self-organizing** activities in the Bayview classroom. As mentioned previously, schools are still organized for the most part around a hierarchy of leadership; with state, district, and building administration mediating curricular and pedagogical demands. In many ways, Bayview was no exception to this hierarchy. These explicit (and sometimes implicit) expectations placed upon Belinda and her students represent some of the 'constraints' that I discussed earlier. However, in the content area of science, while the state had determined that astronomy was a topic to be addressed in 5th grade, the district had not mandated a uniform curriculum, nor did the seasoned building principal choose to exercise significant pedagogical authority over her experienced faculty. The guidelines placed upon the Bayview classroom community were not overly restrictive, and also served as **enabling or liberating constraints**. Belinda, though beginning with a general idea as to what topics she wanted to explore during our time together, did not restrict activities to only those topics. Rather, as students discovered areas of interest, Belinda adjusted her plans, allowing events to emerge and unfold to a great extent; within the general boundaries of curriculum and pedagogy. The ease of access to technology as needed also allowed for self-organization of class members as they often settled into groups searching for similar information on the computers.

Belinda (and I) set the stage early for how she wanted her learning community to evolve, thus demonstrating her **sensitivity to initial conditions**. This meant that Belinda was able to nurture development of this community through practices set up at the beginning of the school year. For example, her classroom was set up in table clusters, with students seated in heterogeneous groups. Though there was an obvious part of the classroom that was 'the front,' Belinda spent little time there, electing instead to circulate among student groups as they worked. Ultimately, this classroom could be said to exist at the **edge of chaos**, in that it was not overly constrained by order, which would not allow for new ideas and directions to emerge; but also was organized enough to allow for an orderly response to those new ideas and practices.

Complexity in a Community of Learners

It is useful to frame the rest of this discussion around Davis and Simmt's (2006) six necessary but insufficient conditions that should be present in a complex community of learners to prompt the emergence of co-activity and innovation. As I related in Chapter Three, those six conditions are: internal diversity; internal redundancy; specialization; decentralized control; enabling constraints; and neighbor interactions.

Internal Diversity

Internal diversity refers to the idea that parts or members of a system have different capabilities. This diversity allows the system to respond flexibly, appropriately, and intelligently to changes in internal and external circumstances. The Bayview students, while not highly diverse in terms of ethnicity or socioeconomic status, brought with them to the classroom community a multitude of experiences and resources; all valued by Belinda. Though for the most part comfortable with computers, past school and home experiences for the students varied in the types of applications mastered and the time spent working with computers. This disparity in experience, typical of virtually all classroom settings, resulted in the students entering Belinda's classroom with a diverse set of skills and abilities with the technological tools that were subsequently used in the classroom. Some students, such as Ethan and Luke, were highly skilled, while others such as Daniel admitted in an interview to not knowing how to type in Web addresses. Similarly, some students were quite knowledgeable about and interested in astronomy, while others had very little experience. In addition, Belinda and I brought our unique and different practices and abilities to this learning system, as did more peripheral community members such as Seth Jacobs (Library Media Specialist), and classroom parent volunteers.

The physical distribution of the computers and their use in the classroom and nearby areas promoted a type of student diversity of experience with the computers as well. Only rarely did all students go into the computer lab in order to work on the same lesson; and even then students were not marching together step by step through an application or drill. Though many of the assignments were set by Belinda, usually around common elements and final products, the ways that students engaged with the tasks and satisfied the requirements for the assignments varied. Students engaged with the computers in different ways as they worked singly, in pairs, or in trios, resulting in varied social and cognitive groupings. Also, Belinda chose to create evaluation rubrics for assignments with diverse input from the students. This could be as informal as asking the students what they thought should be included on a complete space exploration timeline. Or, as in one particular example I related in Chapter Six, where Belinda spent a large amount of time with the students in creating a shared rubric, based upon the district Six Traits for Writing, for the Space Exploration PowerPoint projects.

The wide range and depth of information available to the students via the computers continued to promote diversity in the collective learning community. Most especially in the independent research projects, students were able to follow their curiosity as they pursued their own questions; not those determined by Belinda. In some ways, having 24 students researching different questions was comparatively harder to manage than having a class working on a single question. However, Belinda (and I) believed that the research projects would be far more realistic and meaningful if they came from the students.

In summary, these various forms of *internal diversity* that were created and nurtured by Belinda's teaching practices contributed to the wide range of student astronomy and space exploration projects, and resultant feeling of accomplishment as students took responsibility for their work. Diversity of skill and interest were valued in an atmosphere safe for taking risks.

Internal Redundancy

However, though internal diversity is needed in a complex community, redundancy, or some degree of 'sameness' among agents, is also crucial. This allows agents to interact, and to compensate for others' failings (Davis & Simmt, 2003). In a classroom learning system, this means more than shared vocabularies, symbols, and resources; but also experiences, expectations, and purpose (Davis & Simmt, 2006). In a technology-enhanced environment, these examples should be extended to reflect the introduction of a new resource -- the computer and its associated programs. The software and the user communicate in another shared language based on icons, menus, commands, and routines.

Belinda's years of experience at Bayview, plus the relatively stable student population, provided a type of internal redundancy that enhanced a flexible response to change by both students and teacher as they engaged in the relatively new practice of integration of technology tools into school routines. Due to the presence of a district Technology Plan, most Bayview students had a similar basic working knowledge of the software programs in use in the classroom, though some students were more advanced than others. Also, the district was committed to maintaining a consistent operating suite of Microsoft programs on all computers, with very little room for variation (as we found in our ultimately unsuccessful attempt to install and use RealPlayer on the classroom computers). This meant that commands, menus, etc., were similar across programs such as Publisher and PowerPoint. For the Space Exploration project, Belinda deliberately chose PowerPoint as the organizer for the final product precisely because the students were familiar with the program and then would focus more on the actual content.

Internal redundancy was maintained in the classroom learning system through similar lessons and assignments. Though students were often researching a variety of topics, all were in the same general areas, such as planets or space exploration programs. In addition, data about all the planets were used to construct scale models of the solar system, and entered into a shared Excel file for mathematics assignments. Space exploration programs were placed onto timelines to provide a broader context for all students. The independent research project was somewhat exceptional, but even then there were similar expectations, and all topics dealt with astronomy. Students developed assessment rubrics together with Belinda, and then also shared their projects with each other through the science fair.

In summary, Belinda developed and nurtured a feeling of community and shared endeavor by maintaining similar expectations for all students and their work. Also, students worked together on a variety of lessons around the topic of astronomy; a shared theme throughout the curriculum. Internal diversity and redundancy are similar to the two faces of a coin, with examples of one being closely tied to those of the other.

Specialization

In complex systems, minimum redundancy, or high *specialization*, is valuable in fixed and settled conditions, but would be less than ideal in more volatile settings. Maximum redundancy, or low *specialization*, is advantageous in the face of sudden change. However, dramatically low levels of internal diversity discourage adaptation, or flexibility of response. This concept is closely related to that of a complex system existing on the edge of chaos, i.e., in the place between an area of high order and one without form.

The Bayview classroom enjoyed moderate degrees of diversity and redundancy, and thus could be regarded as relatively stable. The installation of a large number of computers two years previous was considered to be a sudden change, introducing a high degree of volatility. Salomon (2000) discusses the idea of the 'technological paradox,' in which the educational system preserves itself by 'domesticating' technology tools into the established ways of operating in the classroom. Initially, Belinda and her students reacted to these new members of their community in just this manner by utilizing the computers in familiar ways; e.g., word processing, highly structured Web research, typing practice, and Accelerated Reader. This encouraged a higher degree of redundancy and lower specialization of system members: teacher, students, and the computers themselves. By the time I arrived in the Bayview classroom, the computers had become a more regular classroom component. Other members of the classroom system, i.e., the students and Belinda, were then free to become more specialized, with Belinda herself able to encourage a higher degree of specialization through more diverse applications of the computers.

In essence, the timing of my project was fortuitous in this context. Computers had become somewhat regular members of the classroom, and Belinda, her students, and the technology tools were ready for increased specialization as provided in the research projects.

Decentralized Control

In a complex learning system, performing at its best, there is no controlling agent, but rather a "collective phenomenon of a shared insight" (Davis & Simmt, 2003, p. 153). It's really not a matter of a teacher-centered or student-centered classroom. To be an effective teacher in a complex learning system, one does not maintain control, but strives to distribute control throughout the system; allowing for knowledge to be spread across all agents' actions.

Belinda was interested in distributing power and responsibility to her students, while still retaining some overall control of classroom events. Students were involved in the creation of rules for the classroom and rubrics for assignments. In addition, students working individually, and in pairs or trios, were responsible for their own and others' learning. They were given the freedom to work independently and to pursue their own questions, not only those provided by the teacher. Students moved around the classroom freely, from table to computer and back.

The computers also can be considered as agents in the collective classroom, with knowledge distributed across them as well. This perspective is related to the idea of computer as cognitive tool in which learners use technology as a tool for analyzing the world, accessing and interpreting information, organizing personal knowledge, and representing what they know to others (Reeves, 1998). These cognitive tools allow learners to 'off-load' mental tasks, such as memorization of data, to an external resource, the computer, thereby creating an intellectual partnership, in which each partner is responsible for the aspect of learning for which he/she/it is best-suited. In addition, students accessed a wide variety of data via the computers, and had to develop the skills to make their own decisions about trustworthiness of information, rather than ceding that control or power to their teacher. Individual students became more discerning consumers of information, and shared that knowledge with other members of the classroom learning system.

Distributed power in the Bayview classroom provided for a high level of ownership among all members of the learning system. Students' ideas for questions and research were honored by Belinda and others, rather than a specific agenda being imposed upon them. Individual, pair, and group learning took place throughout the day, facilitated by Belinda in her role as an enabling constraint. Though this variability of topics and tasks helped to generate a high degree of student interest, it required that Belinda plan for each student, rather than plan a single lesson for the entire class as a whole. This promoted internal diversity among the students, a hallmark of an adaptive system consisting of a collection of learners. Though in some ways the class could be seen as a holistic, collective learner engaged in the study of astronomy, nested within that collective were unique individuals with their own interests and abilities.

Also, Belinda formally and informally solicited input from students regarding assignment criteria and rubrics. This occurred most formally when Belinda spent a large amount of time with the students in creating a shared rubric, based upon the district Six Traits for Writing, for the Space Exploration PowerPoint projects. This self-organizing, emergent process distributed ownership for the learning process to the classroom community; rather than the teacher holding all grading power.

Enabling Constraints

Enabling constraints determine the boundaries of activity for a learning system, but not limits of possibility. Also referred to as liberating constraints (Davis, Sumara, & Luce-Kapler, 2000) or structures, they "maintain a delicate balance between sufficient organization to orient agents' actions and sufficient randomness to allow for flexible and varied response" (Davis & Simmt, 2003, p. 155).

Belinda's flexibility and adaptability contributed to her skill in operating as a liberating (or enabling) constraint in her complex classroom, which enabled her to decentralize control and distribute power to her students. She worked to maintain a balance between freedom and restraint; to create optimal conditions for learning. Belinda strove to present learning experiences with enough structure to provide direction for the students, but also with sufficient openness to allow for the varieties of ability, experience, and interest that students brought to her classroom (Davis, Sumara, & Luce-Kapler, 2000).

Belinda had particular pedagogical and curricular responsibilities which required her to establish some boundaries on her classroom. However, Belinda encouraged the development of new concepts and ideas with the students to direct the class and individual activities as much as possible. Belinda scaffolded the students as they took more and more responsibility for their learning, defining tasks with limitations and guidelines, while not prescribing student actions or interpretations. Students were free to explore their research questions, but in the context of shared assignments and expectations constructed by and with Belinda.

Other agents acted as enabling constraints in the Bayview classroom, including: Seth Jacobs, the Library Media Specialist who engaged with district technical support personnel and helped us to increase the capabilities of the computers; Margaret Henderson, the building principal who provided enough organization to support Belinda in her practice, while also leaving the classroom community with freedom of flexibility and response to self-organize as needed to learn the curriculum; and me.

My presence in the classroom introduced a new perturbation to an established system; one that encouraged events to proceed in a particular manner and direction. The fact that I was in the classroom to study how the community interacted with technology tools in science resulted in a focus and organization of learning around those two areas. However, I also brought a high level of expertise in those fields with me, resulting in a broader and deeper experience for Belinda and her students. Belinda distributed some of her power as teacher to me, as I acted in the role of second teacher and colleague in the classroom. The flexibility afforded by my presence allowed students to work over a wide area, physically and pedagogically. Also, through specific actions, such as creating and maintaining the Favorites folders on the computers, I exerted some influence on the actions of the students and Belinda.

The concept of enabling constraints can be very broad, with almost any member of a learning system being defined as one. The students themselves operated in this manner, but certainly were not aware of it. The terms of the Gates Grant, which required that the classroom computers be on and ready for use at least 80% of the time, can be seen as an enabling constraint. Ultimately however, it was Belinda as teacher who set boundaries as events unfolded, though these boundaries were not set and followed rigidly from the beginning of the project. Rather they emerged from the experiences of the learning community.

The technology tools in the Bayview classroom can be viewed in terms of the complex nature of the learning environment, with the computers serving as enabling structures or constraints as defined by Davis and others in a variety of publications (Davis & Simmt, 2003, 2006; Davis, Sumara, & Luce-Kapler, 2000). I would argue that an accomplished teacher such as Belinda is far more effective in this role of enabling constraint, but that computers, *if utilized by such a teacher*, can also function as such.

As Davis et al. state, "well-crafted learning activities are ones that maintain a balance between enough organization to orient students' actions and sufficient openness to allow for the varieties of experience, ability, and interest that are represented in any classroom" (Davis, Sumara, & Luce-Kapler, 2000, p. 87). The Bayview computers certainly provided openness, with access to a broad and deep range of information that would be impossible to replicate with print or more conventional means. As related previously, these tools did contribute in the areas of information organization, analysis, and presentation (via Publisher and PowerPoint); and also in the visualization of intricate relationships such as Earth's seasons, lunar phases, and solar system movement.

Where it could be argued that technology tools may fall short as enabling constraints is in the area of organization of data from the Web. As related in Chapter Six, many students encountered difficulty in finding information. This was due to a variety of factors; the most important being variable competence in student search abilities; and also the sheer amount of information available on the Web. As students honed their skills, searching became easier, but this was still a problem.

Highly motivated and competent students may very well be able to learn successfully on their own with computers. However, computers alone cannot serve as a replacement for teachers. Teachers are needed such as Belinda, who can creatively integrate computers into her instruction, structuring those 'well-crafted learning activities.'

Enabling constraints are seen as boundaries of the learning system, but not limits of possibility. In one particular instance, that of the attempt to install RealPlayer on the classroom computers, the Bayview school district limited the possibilities for Belinda's classroom. This episode illustrates the intersection between the restrictive, linear, and hierarchical structure of the school district, and the complex, emergent technology-enhanced structure of the research classroom. A relatively large school district justifiably sees the need to protect and maintain their technology investment; while an adaptive teacher wishes to nurture and develop her students' use of technology in an innovative and productive manner. In this case, the district operated as an inhibitory constraint, rather than as an enabling or liberating, structure.

In summary, the order that emerged in the Bayview classroom was determined by Belinda, the students, me, and other more peripheral agents. Belinda and I were both willing to gently guide the students, but we did not wish to travel solely to preordained destination(s).

Neighbor Interactions

Neighbor interactions involves the notion of a sufficient density of ideas interacting with one another to create new meaning. This is necessary feedback to the system, which shapes and reshapes the ideas represented by the collective. As the ideas interact, understanding and interpretation of the concept by both the individual learners and the classroom system are enhanced. In order for effective neighbor interactions to take place, the Bayview classroom provided a safe space to take risks.

The level of content integration across subject areas provided for an immersive, holistic learning environment, in addition to opportunities for neighbor interaction in the form of ideas and concepts expressed through a multitude of learning modes (Davis & Simmt, 2003, 2006). The elementary classroom, in which most subjects are explored by a single teacher and his/her students throughout every day, presents an ideal environment for this level of density in a topic. Integration allows for sustained study over time, without need for division of work into period-size chunks as usually occurs at the secondary level. Topic focus across subjects allows students (and teacher) to enter the area of study from different directions, or personal curricular strengths. Most importantly, working with astronomy and related concepts throughout most of each day, provided through a variety of experiences, perspectives and inputs, helped students to make connections as they engaged with ideas in different ways.

Though seating students in table groups does not automatically provide for neighbor interactions, it did help that the Bayview students worked together and in close proximity on almost all projects. I would also argue that pair and trio work on the computers encouraged free and easy discussion of concepts and learning strategies. This was not a quiet classroom, but one in which students, Belinda, and I were often discussing the learning that was occurring. Central to this were the ideas of shared work and power, but also that of taking risks in learning. Students regularly presented their work to each other, resulting in many comments of recognition and agreement as students saw similarities with their own projects. Their ideas, concepts, and representations (of knowledge) were then able to 'bump up' against each other through neighbor interaction, resulting in a richer learning environment.

The technology tools themselves provided a vast amount of information, but it could have easily dissipated or remained personal without the boundaries and connections of the community to contain and nurture this knowledge. As students shared their data and ideas, they took on new and varied meanings, traveling from member to member in the Bayview learning system. Also, though students were working on different topics, they were within similar areas, which allowed for interaction of related concepts and ideas (Davis & Simmt, 2006).

Summary

Complexity theory has allowed me to interpret and understand events in the Bayview classroom in ways that I had not imagined previously. When I embarked on this project, while I considered myself to be a constructivist teacher, and I made every attempt to distribute power in my classes, I did not yet see the classroom as such a collective community. The concepts of self-organization, internal diversity and redundancy, specialization, decentralized control, enabling constraints and neighbor interactions allowed me to examine and interact with this classroom as a collective whole, but also to explore the interactions of its members, in order to make some real sense of events as they unfolded. Previously, I had a tendency to focus on the teacher, the students, the curriculum, physical organization of the classroom, etc., in isolation. I often wrestled with the concepts of student-centered and teacher-centered, and perceived them in opposition to each other. With the insight afforded me by complexity theory, I see now how a classroom community as a whole exists at the center, which has broadened my interpretations of research.

In the open Bayview learning system, complex adaptation and change were continually occurring in all members: the students; Belinda; and in me, as the researcher. The computers, with their continuing flow of information and experience, provided for a great deal of the open nature of the emergent classroom community. Also, the way in which Belinda and I structured this experience, to allow for new and unique ideas, practices, and learning to emerge as we worked, provided for a rich, diverse and adaptive experience in the fertile area on the edge of chaos.

Chapter Eight: Conclusions and Discussion of the Study

In this final chapter, I provide a brief overview of the research problem area; once again lay out the research questions; and then delineate the conclusions I have reached through this research study. Lastly, I situate my research in the literature, followed by a brief discussion of further research possibilities.

In this case study, I explored the practices of an elementary teacher, Belinda Knudson, and her 24 students as they worked to use technology tools to enhance science instruction and learning; specifically in the area of astronomy. My research questions were structured to allow for items of interest to emerge within a complex framework. This was not an evaluative study in which I endeavored to answer questions about which applications worked best, or what methods of teaching were better for learning. To reflect this emergent perspective, my research questions were the following:

1. How can the imaginative integration of technology tools extend the practices of a teacher and students in an elementary science classroom? How do these teacher and student practices interact?
2. What conditions/structures were present in this case to nurture the development of technology as an imaginative extension of the complex learning environment? How may these conditions be considered as 'enabling constraints'?

In this research, I used complexity theory as a lens through which to interpret the events and practices which emerged in the classroom. Complexity theory or science "deals with self-organizing, self-maintaining, adaptive phenomena – in brief, with systems that learn" (Davis & Simmt, 2006, p. 295). The Bayview classroom was a dynamic system, exhibiting many of the characteristics of a complex entity; thriving in the fertile space at the edge of chaos.

Conclusions

Research Question 1: Extending the learning practices of the teacher and the students

Technology as an extension of practice

The technological tools in the Bayview classroom extended the practice of Belinda and her students by providing an **immense data source for research projects,** easily **accessible** to everyone. These data, for the most part available through high-speed Internet connections, were of all types: text, video, audio, simulations, etc. Some of this information was of a primary nature, not pre-packaged by an educator. This diversity of data types allowed students to enter their research tasks from a variety of learning perspectives and abilities. Belinda was able to guide students to individualize their learning as they explored topics of interest to them; resulting in an increase in internal diversity for the classroom community.

Also related to the research projects were the **representational, technological tools** of Publisher and PowerPoint™ that enabled students to make polished products for their presentations. These applications functioned as a form of semantic organizational tools, and at times, knowledge construction tools as well. These tools also enabled the students to develop a sense of pride and ownership in their work as they presented the results of their projects to a variety of audiences.

The **electronic nature** of the student products enabled the in-depth, and at times unending, research projects that were housed and stored on school network drives. Students continued to 'tweak' projects long after they were officially completed and assessed. At the end of the year, the student drives were to be purged, but exceptions were made as students requested them. Also, as the projects were made available on the class Web page, students often explored their classmates' work.

In summary, technology tools extended the practice of all members of the Bayview classroom. Without easy access to these tools and the tremendous amount of resources they provided, the heightened level of research, preparation, and presentation of data would not have been possible.

Teacher and Student Practices Extended through Technology Tools

Teacher practices

Belinda's teaching practices did not change completely due to the introduction of the computers from the Gates Grant in her room; in fact many of her existent practices encouraged imaginative integration of the technology tools. While large scale change in teaching practice is not the question here, it is illuminating to look at the many instances of where the use of the technological tools interacted in important ways with both Belinda's practices (and subsequently her students' practices), resulting in significantly different classroom behaviors by both, as compared with previous, less technology-rich environments.

On a basic level, Belinda's practice needed to accommodate the computers and their use from a physical space and **management** perspective. Those in the classroom were considered a resource to be used by students as any other, with no need to ask special permission. However, Belinda asked students to seek permission before using those in areas outside of the classroom. There was much student movement to and from various computers, which at first was quite distracting for Belinda, but her flexible management practices served her well here.

Despite being a Gates Grant recipient for the two previous years, it really wasn't until this research year that the computers became part of the natural environment of this Bayview classroom. As Belinda stated in our Oct. 15th interview, "it's becoming even more natural to use it [the computers]on a regular basis and the kids are becoming more natural with it." In the previous years, Belinda had not used the computers as an integral part of her science curriculum; they were more of an add-on "if we had time." Belinda reported this change as a steady progression, as more and more uses for the computers emerged. What appeared to aid this process was the flexibility afforded by having eight or nine computers in the classroom, plus four more in the 'stage' area, "for just jumping on;" but also having a full computer lab nearby when everyone needed to be on at once (11/26/02 interview). This allowed Belinda to use the technology far more than in previous years, and in different ways.

When I asked Belinda if she could teach now without the computers, she said, "it's kind of hard to imagine, actually. This becomes natural, part of what you do. It's not an add-on. It's part of the curriculum" (11/26/02 interview). In February 2003, Belinda reported that the class rarely did a writing project without the computers, and that she wouldn't have it any other way.

These computers provided an enormous **breadth and depth** of up-to-date information for the classroom community; enabling an almost infinite range of research topics in astronomy and space exploration for students. Without that breadth and depth, the research projects as undertaken by these students could not have occurred. Belinda was confident that she and her students could find information about virtually any topic of interest. This allowed her to plan instruction without being constrained by limited personal or school resources.

The level of information available promoted the development of more in-depth projects for students, which took place over a longer time period. Supervision of these student projects meant that Belinda adjusted her planning accordingly; providing students with scaffolding as they completed small pieces of these longer assignments each day. As Belinda stated:

> I think that the assignments have changed a lot because . . . (there aren't) as many short, little assignments . . . where there was, like, paper, do a little project and write about it or something. I think that I have looked at it more from the long-term project standpoint, I guess, and that kids will have more opportunities to delve into things that they really find interesting within a topic, whereas I don't think I did that as much when I didn't have the technology because I really didn't have the resources or I didn't feel comfortable saying 'Oh, yeah—you can go search about that and find information.' It was like 'Okay. We're learning this today' (2/23/03 interview).

The technology-based assignments that the students did during this research period were indeed lengthy; customarily taking three to five weeks to complete. Interestingly, most students completed their independent research projects only because there was a date for them to be finished. Many told me that they were still interested in their project, and wanted to do more with them. Of course the most extreme example of this was the Solar System Cataloging project, which continued through the rest of the year.

Though the earlier research projects were closed-ended, with specific goals in mind, the last independent project was quite open, with only basic presentation parameters determined. Students were able to research a wide **range of topics** for their individual projects; presenting management and pedagogical challenges for Belinda. The class was no longer being guided together through the same materials, but was scattered over a broad range of projects of varying demands. These Web-based sources usually were not pre-selected by Belinda, nor did she necessarily know a great deal about all student topics. In our discussions and interviews, Belinda often talked about her role as a guide for students, as opposed to a dispenser of knowledge. She became comfortable with **students learning things that she didn't know**, and believed that the students enjoyed that aspect of the computers.

These issues provided the potential for **unending research** projects, as illustrated in the 'Cataloging the Solar System' endeavor. Not only was there no realistic end to the information about the solar system that these students could gather, but the final product was an electronic PowerPoint™ file that could be endlessly constructed and edited. For all of the electronic projects, Belinda needed to decide (along with her students) when to stop and assess student work. **Assessment** of student work was adjusted due to the nature of research possible. Students were expected to do more synthesis of information from a variety of sources, rather than merely repeating facts. Belinda was able to adapt existent rubrics, such as those for Six Trait Writing, as she did for the Space Exploration PowerPoint projects.

In general, technology enabled a series of projects of an expanded and open nature; within the context of an adaptive learning environment. Belinda made a number of significant modifications to her existing practices to accommodate the changes that occurred in her instructional roles and tasks that were brought about through the extensive use of computers in this unit of work.

Student practices

Again it is illuminating to examine the many examples where the use of technological tools interacted in significant ways with the students' practices, rather than to look solely for large-scale changes that may have occurred. For the most part, the Bayview students were reasonably adept in their use of computers, resulting from their school experience and access at home. However at a basic level of access, no K-3 classroom at Bayview had such computer capacity as Belinda's classroom; with the accompanying opportunities for independent research and extension of technological abilities. Belinda also set the tone early that the computers were a learning tool, to be treated as any other, resulting in a feeling of collective ownership. Students demonstrated this ownership and responsibility by troubleshooting technical issues, and by placing different wallpapers in the computer backgrounds.

The **breadth and depth** of the information accessible to students resulted in different expectations for student work. Belinda expected some **long-term** projects that spanned over a period of weeks, rather than days. This meant that students had to learn new ways of managing their time, working independently of adults, and remaining focused as they worked toward a more distant goal. This would have been true for students of this age without this level of technology, but most likely not to this extent.

Knowing that information about virtually any astronomy topic was available was empowering to students. However, in some ways this was too much of a good thing. Due to underdeveloped search strategies, and challenges in determining information reliability, students encountered difficulty in finding desired information through tools such as Google. Though Belinda was there to help, students were often expected to work independently in pairs or trios, rather than being led as a class through materials. At times, **students became the experts**, knowing more than their peers or Belinda about some topics. This was enjoyable for the students, especially when they posted their work on the class Web page, and **presented to audiences** of peers, school community members, and parents.

Though most students had previously constructed brochures with Publisher, or made PowerPoint™ presentations; they strove to create a final product that was polished and professional. However, the deeper level of research, synthesis and writing required for the projects was a newer challenge. Fortunately, **assessment** rubrics were jointly created by the students and Belinda, which made desired characteristics more clear.

In summary, students expanded and deepened their research skills and technological abilities through their extensive use of computers in this astronomy and space exploration unit. Though most students had used computers, performed research, and presented to peers before, they had not done so at this level of sophistication.

Interaction of teacher and student practices

As was the case with Belinda, the students also learned to be tolerant of the potential distractions caused by classmates' movements from table groups to various computers in and out of the classroom; though a few continued to have difficulty with maintaining focus. The classroom community settled on practices and routines which made this **flow** of activity smoother.

More importantly, teacher and student practice in the area of research itself grew and developed under the influence of technology tools. Having a data source that was accessible to all members of the community provided for projects more similar to '**real scientific research'** in that:

- as students looked for answers to their question, they discovered more questions
- students often learned things that Belinda did not know
- projects were long-term, often lasting many weeks, with smaller tasks being completed each day

- students often worked together in teams, or at least shared some of the data they found with other students
- students presented their work to their peers and to other interested community members
- additional questions often had to be 'left on the table' to research later.

This last point is related to the potentially unending nature of research when more open-ended activities are provided and limitless information is available. Belinda and her students had to decide how much and what types of information were needed for a completed project, and then stop using class time for the work.

The **presentation of student projects to peers and a wider audience**, both in-person and electronically, provided a rich and authentic experience for Belinda and her students. Too often student work is prepared solely for the teacher, with very little dissemination to other students or adults. Students were justifiably proud of their work which was considered to be good enough for many others to see. In addition, Belinda was able to share the work that she had been doing with her students with her Bayview colleagues and student family members.

As Belinda compared these computer-based projects to those she had done before she had the classroom computers, she said:

> There was never much "there" there—there were never more questions [in the old projects]. It seemed like *this* whole inquiry just built upon itself. It was like we started with a question and then the question led to more questions. Things got answered, but then you went in other directions -- and so the students helped build that along. We would just list those questions on the chart paper and it was like -- never ending. The students were very motivated by that, too, because it was like

"Gosh, I really want to find the answers to those questions." You know? So it did really change the way I was doing my instruction and the way I would think about different sorts of things (2/23/03 interview).

This is emergence at its finest. Students were presented with a beginning point, given supportive structures, but few limitations, and then encouraged to explore their interests to see where they took them. It was technology that enabled that to happen in this classroom. Without speedy and reliable access to the Internet and its multitude of resources, such a broad range of research would be impossible. Also, a single computer in the classroom would not have provided the needed seamless integration into the regular school day. The same is true for the computer lab approach to technology. If the students had had to wait to do their research at a structured and limited time each week (or day if they were fortunate) in the lab, the process would have been artificial and stilted. With this arrangement, transitions were fluid and natural; allowing Belinda and her students to use the best resource for the task at hand.

Research Question 2: Conditions of complex learning environments

Conditions to Nurture the Development of Technology-Rich Learning Environments

Physical arrangement and working with others

The **number, placement, and availability of the computers** mattered. Eight or nine machines in the classroom were adequate, but only because of the additional computers that were available on the nearby stage and lab. The classroom computers, which were always on, were distributed throughout the room, not isolated into a 'computer area' or out in the hall. This made them available for student use whenever needed, and also allowed Belinda and I to supervise the students to some extent as they worked. Normally, students worked in pairs or trios on the computers, as that was how most assignments were configured. Also, the classroom computers were close together due to space limitations, promoting social and academic interaction. Rarely did students need to work alone on a computer, but if the task demanded it, the computer lab was nearby. These physical arrangements and ease of access allowed for self-organization and fluidity of classroom work; from individual to pair and group work; either with or without the computers. If the classroom had been equipped for example, with 24 laptops, this fluid social and academic movement may not have occurred, perhaps interfering with the development of the classroom collective community.

For the most part, **students preferred to work with a partner** on the computer, unless they were involved in a more solitary activity such as writing poetry. Most students, who were already accustomed to working with partners or groups in general, saw working with a computer research partner as a way to divide the labor and finish the project more quickly. I have often thought of working on the computer as an individual activity, as that is how I customarily interact with it. Perhaps as students continue to work on computers in a social context, the image of such work as being isolating will recede. If students learn using computers in a social context, working literally together on a single machine as did Robin and Tara, will this result in computers being perceived as a shared, social tool? Will the current common image of a single person working at a computer in physical isolation recede? Already, through social networking made possible by the Internet, computer users form a wide variety of virtual communities. Perhaps computers, rather than being an isolating factor, will become more of a link in the social fabric; with that classic image of students seated at individual computers facing the walls of the computer lab slowly disappearing.

Freedom to self-organize

The complex system of the Bayview classroom allowed the extension of practice through technology discussed in this dissertation to emerge. However, other factors contributed to Belinda's creation of this learning environment.

First, due to the low priority of science at the state and district level; Belinda, the students, and I were able to experiment, to take risks, and integrate the instructional environment heavily with technology. Second, as Belinda was receiving no Gates Grant professional development with her computers, no specific curricular demands *in technology* were placed upon her. Third, the experienced and supportive Bayview principal allowed her veteran teachers to teach independently. Last, our research context was an elementary classroom, which meant that if Belinda chose to integrate all subject areas through projects in astronomy and space exploration, she was free to do so.

With this level of independence and flexibility, Belinda's teaching practices required her to maintain a **balance between freedom and restraint**; to provide learning experiences with enough structure and sufficient openness to allow for varied levels of learning in her students. Belinda recognized the importance of her role, often verbally reflecting upon her own adaptability and openness to change. My presence as a colleague and researcher also impacted this balance for Belinda, providing support for her experimentation with curricula and technology tools.

Discussion of Results

The Bayview Classroom in a Technology Context

As I related in Chapter Two, at a fundamental level, a good study of student learning in a technology-rich context needs to focus less on establishing that particular situations are 'better' than non-technological situations, and more on establishing two ideas: first, that the technology-rich context makes possible something different than what would be possible without technology, and second, that students can and do succeed in learning the concepts the technology-rich situation is designed to help them learn (Culp, Hawkins, & Honey, 1999). The point of using technology, developers and proponents argue, is not to do what we have always done conventionally, but rather to provide kinds of learning experiences that are impossible to provide in any other way (Means, Haertel, & Moses, 2003).

Some of the work done by Belinda and her students in the Bayview classroom conceivably could have been accomplished without technology tools. However, to gather such a wide and diverse array of information would have required an incredibly large amount of resources; acquired at a great financial cost. Also, we established that the creation and sharing of PowerPoint™ presentations was a far richer and cognitively demanding task than the compilation of a conventional written report or poster. In addition, though no direct comparison can be made with a non-technology class studying the same topic, it was clear to Belinda that these students learned far more about astronomy and space exploration than did her previous students, without benefit of technology resources.

Students learn best when four basic characteristics are present: a) active engagement in learning tasks, b) collaboration in groups, c) frequent interaction and feedback from the teacher, and d) connections to real world contexts (Roschelle, Pea, Hoadley, Gordin, & Means, 2000). The structure and resources of traditional classrooms often do not provide these conditions, while a technology-enhanced environment such as the Bayview classroom *can, and did,* enable ways of teaching that are better matched to how students learn.

The experiences of the members of the Bayview classroom as described in this dissertation are strongly related to these characteristics. The classroom computers certainly enabled students to engage in projects that would not have been possible without them. Also, as assessed by Belinda and me, the students satisfactorily demonstrated their understanding of astronomy and space exploration concepts. The students, often working collaboratively, were actively engaged in their research projects, which were situated within the context of real data from authentic sources. Belinda and I consistently provided feedback for the students, as did their peers, throughout the research process.

The use of computers in the Bayview classroom falls firmly in the context of learning "with" technology; most specifically in the category of cognitive tools or *mindtools* (Jonassen, 2000; Jonassen, Carr, & Yueh, 1998; Jonassen, Howland, Moore, & Marra, 2003; Reeves, 1998; Ringstaff & Kelley, 2002; Salomon, Perkins, & Globerson, 1991). This kind of learning **with** computers supports knowledge construction, explorations, learning by doing, learning by conversing, and learning by reflecting as intellectual partners (Jonassen, 2000). The Bayview students were supported by the technology tools (and Belinda and me) as they constructed their ideas about astronomy in the social context of the classroom community. In the following section, I discuss how Jonassen's *mindtool* categories relate to technology use in Belinda's classroom.

Mindtools

The members of the Bayview classroom utilized a variety of technology tools during our exploration of astronomy. It is helpful to classify how the students worked with computers in terms I discussed in Chapter Two, most specifically those in the system of *Mindtools* delineated by David Jonassen. These categories include, a) semantic organization, b) dynamic modeling, c) information interpretation, d) knowledge construction, and e) conversation and collaboration tools (Jonassen, Carr, & Yueh, 1998).

Semantic organization tools

Semantic organization tools help learners organize and analyze what they know and what they're learning. Students may interrelate ideas, label relationships between concepts, and describe the nature of relationships between all ideas in a network. Examples of semantic tools are databases (such as FileMaker Pro), concept mapping tools (such as Inspiration), and presentation tools (such as PowerPoint). I would argue that PowerPoint can also be placed in the knowledge construction category, though in some instances PowerPoint belongs in this group. For example, when doing research about specific space exploration programs, students gathered and analyzed information, then needed to interpret and organize their data so that they could be presented to an audience. Students demonstrated success in generating a series of PowerPoint slides that flowed one from another in a coherent presentation. Guidelines developed by the classroom learning community in order to provide structure for the PowerPoints aided this process immensely.

Dynamic modeling tools

These tools allow the learner to express dynamic relationships between ideas, and include spreadsheets and modeling tools, among others. Data gathered for the student planet brochures were entered by Belinda into an Excel spreadsheet, and then used in graphing lessons in mathematics. Also, Starry Night software was used by the students to explore the relationships between solar system members, and to model lunar phases. The change in the Moon's shape throughout its cycle was observed and recorded (sky conditions and timing permitting) by the students. However, Starry Night allowed students to observe multiple cycles over many 'days' on the computer.

Information interpretation tools

These tools help the learner to access and process large amounts of information, specifically through Web browsers and visualization tools. Students demonstrated a varying degree of proficiency with using Internet Explorer and sites such as Google to find information, with a few becoming adept at using the Google advanced search capabilities. Also, the use of Starry Night software allowed for a visual and animated presentation of a large amount of data which would be difficult to synthesize in its raw form. For example, when students looked at the class Excel spreadsheet of planetary data and statistics, it was relatively easy to see that Jupiter was the largest planet. However, its size relative to the other planets was far more apparent by using the visual scale representation provided with Starry Night.[39]

Knowledge construction tools

These tools aid the learner in building their own knowledge, and include multimedia, desktop publishing, hypermedia, and related technologies. These are used not in knowledge reproduction, but in knowledge *construction.* Though Jonassen does not specifically include PowerPoint™ projects in this category, I would make the argument that they can be placed here, and also in the category of semantic organization tools as I related previously. While it may appear that students did merely gather data, guided by Belinda, and then organized them into a PowerPoint™ presentation for an audience, I would also argue that students synthesized information from a wide range of sources to construct their own understanding of the object under study. This was particularly evident in the independent research projects created by each student. It was apparent in the Science Fair presentations (some of which

---

[39] Of course, working with concrete scale models in the physical construction of the scale model of the solar system was invaluable.

included a PowerPoint™ component) that each child learned a lot about their chosen topic, and that most had explored a wide array of data sources to find what they wanted to know. Then, organizing their information into a PowerPoint™ presentation supported their construction of knowledge.

A more convincing example would be the Cataloging of the Solar System project undertaken in parallel to the regular events of the classroom. Initially, Ethan, Gabriel, and Luke organized their data into a series of PowerPoint files; which did serve in a semantic organization capacity. However, as time passed and the project became larger, the students realized that they would need to revise and refine these files into one coherent whole. Many times I observed these three boys poring over their slides as they made connections between data they had found. Though never formally assessed, I do believe that Ethan, Gabriel and Luke constructed a great deal of knowledge about the solar system; the characteristics of the planets and their moons, asteroids, comets and the relationships between all of these.

A small additional item is that many of the PowerPoint™ slideshows constructed by the students over the research period contained multimedia elements. I would argue that the boundaries between semantic organization and knowledge construction tools are somewhat hazy, and that PowerPoint™ can belong in both categories, depending on how it is utilized.

Conversation and collaboration tools

These include synchronous and asynchronous communication tools such as videoconferencing, online chats, instant messaging, and e-mail. This was an area which was not utilized as much as Belinda and I had hoped. Consider our failure in the area of online chats with astronauts using RealPlayer™ software. In the planning stages for this project, Belinda and I believed we would be studying water, rather than astronomy. Therefore we had made plans to share various data online with other schools and communities in North

America. No comparable outlet existed for astronomy. Students did communicate via e-mail with a few 'experts' found on various websites. Also, I facilitated an e-mail conversation between a student, Scott, and a friend of mine at the Jet Propulsion Laboratory, around Scott's research topic of astrophysical jets.

Teacher Professional Development and Educational Technology

Belinda held a Master's Degree in educational technology, though she had gained surprisingly few pedagogical skills for using technology from the experience. However, she was an experienced and reflective teacher, and enthusiastic about trying new approaches and implementing technology practices that supported her curriculum objectives. Teachers must play a **central role** in deciding how to implement the integration of technology tools within their classroom context (Kimmel & Deek, 1995; Mayer-Smith, Pedretti, & Woodrow, 1998a), and Belinda was committed to that integration into her science curriculum.

As Belinda was not receiving professional development with her equipment, my research project served as a professional development experience for her, though that was not my intent at the outset. Belinda was in her third year with the new computers, so we were not starting from the beginning, but I found that she needed all of the elements of technology professional development that I delineated in Chapter Two.

Adequate **time** to explore new tools and acquire skills to implement technology should be provided for teachers. Even though this was the third year, and she had had some time to develop skills, we still found time to explore in depth in short supply. Our work together in the classroom did provide for a high degree of **flexibility** as Belinda integrated more technology into her pedagogical practice. Mentoring, peer collaboration and collegial **support** have been identified as positive models of professional development (Brand, 1998; Ertmer & Hruskocy, 1999; Franklin & Sessoms, 2006; Mayer-Smith, Pedretti, & Woodrow, 1998b; Pedretti, Mayer-Smith, & Woodrow, 1999; Schrum, 1999; Thurlow, 1999), and as a participant researcher I fulfilled that role for Belinda. Being in her **classroom context** for many days over a **sustained** period of five months allowed me to support Belinda as needed. In addition I functioned as a colleague in the planning and implementation of the astronomy and space exploration curriculum, while always striving to remain aware of my status as a researcher. However, my presence ultimately did bring about change in Belinda's practice, as I discuss in the next few paragraphs.

Belinda often commented that my presence encouraged her as we worked together to implement more technology use in science. This was perhaps inevitable, as we never intended that I be the impartial observer on the outside looking in. What I saw as little things I did to contribute were often seen by Belinda as major benefits. For example, when I set up the Space Favorites folders on the computers, I saw it as a small thing to help the students find good information. However, Belinda brought that up as a crucial teaching tool that she would use in all topic areas in the future (10/15/02 interview). In addition, just having me in the classroom automatically provided an emphasis on technology and science, resulting in Belinda being more focused on technology, and the new opportunities afforded by it (11/26/02 interview). As Belinda also stated, my presence helped her to focus on content a lot more, as she knew that I was very knowledgeable about astronomy, which made her feel like she was honing her skills too. Belinda felt that she could continue her work in technology and astronomy, because she became aware of just how many different opportunities were available (11/26/02 interview).

My presence as a colleague in the classroom relieved some of the isolation of Belinda's position. Even though Bayview is a small school, teachers have very little time to spend together; very rarely do they have the luxury of being in one another's classroom. As

Belinda said, having me in the room "was relieving for me in a way, because...I don't have to be doing everything all the time – it's been really nice planning with someone else – and being able to bounce ideas off of each other while teaching" (9/10/02 interview). We often adjusted things 'on the fly' as we were working with the students, as we could look to each other for support, "because otherwise you look to the students for feedback" and that is from students, not another teacher.

I believe that I emboldened Belinda in her approach to the classroom technology tools. By nature, I am comfortable tinkering with computers and other equipment. When issues arose with the computers, I would try to fix it myself; or perhaps ask an adept student such as Luke for help. This encouraged Belinda to be more assertive and self-reliant when it came to repair issues in her classroom. Another example would be our search for the LCD projector during one of my visits after the project was over. When Belinda related that she knew there was a projector in the school somewhere, it was I who suggested that we search throughout the building for it; knowing from previous experience what an effective tool it could be in her classroom.

This research served as a professional development experience for Belinda. There is now "general agreement that the most powerful staff development is job-embedded – teachers learning together as part of their routine work practice" (DuFour, Eaker, & DuFour, 2005, p. 248). As Belinda stated, she was interested in doing this project, "as us working together will be a big support...I think the job-embedded staff development is the way to go...workshops are great, but while you're doing it, is where you'll really benefit the most from getting more support" (8/21/02 interview). I am pleased that I was able to provide such a resource for Belinda, but I consider that small payment for what I gained from this research experience.

Recommendations

My research provides an example of how one elementary science teacher incorporated technology tools into her practice. As Zhao et al. state, "there is a conspicuous lack of attention to the complexities and intricacies of how classroom teachers actually incorporate technology in their teaching" (2002, p. 483), especially in science at the elementary level. Through my work in this case study, I believe that some very specific recommendations for technology use can be made.

An adequate number of classroom computers should be present to allow all students to work on them at the same time. However, a 1:1 student to computer ratio is likely not appropriate, as the social context of computer use promoted learning at Bayview. Computers should be: a) up to date, b) reliably in working order, c) connected to a reliable high-speed network, and d) have similar software (and versions) available. It is important to have knowledgeable school-level technical support (as provided by Seth Jacobs at Bayview), with responsive district-level support for more advanced issues.

There has been some disagreement in the literature about classroom vs. lab-based computers (e.g., Rule, Barrera, Dockstader, & Derr, 2002; Salomon, 1990; Watson, 1990). Some research has shown that the distributed model, with computers located in classrooms rather than in dedicated computer labs, is the most effective (Ringstaff & Kelley, 2002). My research supports this finding, but I would also argue that a mix of classroom and lab-based computers is ideal, if adequate funding is available. This allows students to work as needed within the classroom, but also allows the teacher to access a lab in which all students can work together on one project, but interact with the computer individually. In addition, classroom computers themselves should be distributed throughout the room, rather than in an isolated area such as a hallway.

Teachers need more than a year or two to explore all options of how to successfully integrate technology into instruction (Sandholtz & Ringstaff, 1996), and the case of Belinda, who was in her third year with the computers, supports this assertion. The freedom given to Belinda, allowing her to experiment over time with how the computers could work with her and her students, was crucial as well. In some ways this freedom resulted from a lack of professional development for Belinda, when such support can be crucial if the tools are to be used. However, Belinda was committed to using the computers in her classroom, and my presence unexpectedly provided contextual, embedded professional development in her classroom.

Future Research

On a personal level, I expect to apply these ideas and concepts in my own career as a program evaluator, teacher, and researcher in the classroom. As I reflect on my past experiences as a teacher, I see so much that I missed then. The dynamic interplay between members of a community has always been of interest to me, and this research has provided me with valuable tools and images of teaching and learning.

Specifically, the social context of computer use is of interest. In this research, I found that it was not necessary to have one computer per student, and perhaps it was best to have only enough to allow children to work in pairs or trios. It would be interesting to explore how a 1:1 ratio with wireless student laptops would affect the social context of learning science in an elementary classroom. Would students interact with each other, or would they isolate themselves into individual projects?

Also, though simulation software was not a major focus of my research, I would like to explore how students might interact with a program such as Starry Night in a more formalized context. The use of Starry Night in the study of lunar phases with adult learners has been researched (Bell & Trundle, 2005; Trundle & Bell, 2005), but not yet with younger, intermediate students. Students in the Bayview classroom were for the most part able to describe the motions of the Earth and Moon using physical models. However, long-term moon observation journals were not kept due to time and weather constraints. Would the use of Starry Night in conjunction with physical observations of the Moon and its phases by an upper elementary class improve their understanding of lunar phases?

There is a body of technology literature dealing with how pedagogical styles of teachers interact with ways of technology use in the classroom. As I wrote in Chapter Two, it has been found that teachers who are computer users exhibit constructivist practice, including collaboration, project-based work, and hands-on activities (Honey & Moeller, 1990). It has also been reported that constructivist-oriented teachers use computers in more varied and powerful ways, have greater technical expertise in their use, and use computers frequently with students (Becker, 2000). According to Ringstaff and Kelley (2002), "more advanced uses of technology support the constructivist view of learning in which the teacher is a facilitator of learning rather than the classroom's only source of knowledge"(p. 9). Belinda would certainly be an example of this, but are teachers who use computers more likely to be constructivist in the beginning; or can computers promote constructivist pedagogy?

Though my research was limited to the Bayview classroom and its members, other peripheral members had an impact. Specifically, the Library Media Specialist, Seth Jacobs, was very supportive of Belinda and her students. Seth interacted with all students (through computer lab lessons) and staff at Bayview, and his role was crucial to technology implementation. It would be interesting to pursue a line of research about school staff members such as Seth, perhaps examining their role as a type of enabling constraint between the district, school and classroom.

On a larger scale, I believe that the perceived role of technology tools in the classroom continues to develop. Computers that were once seen as new and novel are now commonplace. Though the 'digital divide' continues to be of concern, the gap is narrowing on the national scale. As of 2005, the national average for student per high-speed Internet-connected computer was 3.9 : 1. However, that ratio for *classroom* high-speed Internet-connected computers climbs to 8.0 : 1 ("Technology Counts ", 2006). Due to this lower ratio, the current U.S. government administration has been reducing the funding available for educational technology through programs such as Title IID Enhancing Education Through Technology ("ISTE Members Impact Positive EETT Vote", 2006), while increasing accountability for schools through the No Child Left Behind act.

In this time of fiscal and accountability constraints, it is important to determine and disseminate effective ways of using the technology tools already in place. Continued research from an ecological perspective which examines the integration of computers into teacher and student practice is needed. The field of education tends to be impatient, with new programs and curricula introduced long before older ones have been thoroughly implemented, supported, and evaluated. Again, it is important to pay "attention to the complexities and intricacies of how classroom teachers actually incorporate technology in their teaching" (Zhao, Pugh, Sheldon, & Byers, 2002).

Final Thoughts

While technology may make learning easier, efficient, and more motivating, ease and efficiency are not prerequisite conditions for deep and meaningful learning. Learning is not always easy or efficient. It is important that educators and policy makers understand and recognize the complex nature of technology's impact on student outcomes (Schacter & Fagnano, 1999). Technology tools cannot be considered in isolation. By using the perspective of complexity theory in this research, I have shown that all elements of a classroom: the teacher, students, curriculum materials, technology tools; along with other more peripheral members of the learning system, must be considered as a body of interconnected parts.

Bibliography

Abell, S. K. (2000). From professor to colleague: Creating a professional identity as collaborator in elementary science. *Journal of Research in Science Teaching, 37*(6), 548-562.

Adler, P. A., & Adler, P. (1987). *Membership roles in field research.* Newbury Park, CA: Sage.

American Association for the Advancement of Science. (1993). *Science for all Americans.* New York: Oxford University Press.

American Association for the Advancement of Science: Project 2061. (1993). *Benchmarks for science literacy.* New York: Oxford University Press.

Apple, M. W. (1998). Teaching and technology: The hidden effects of computers on teachers and students. In L. E. Beyer & M. W. Apple (Eds.), *The curriculum: Problems, politics, and possibilities* (2nd ed., pp. 314-336). Albany, NY: SUNY Press.

Arthur, W. B. (1999). Complexity and the economy. *Science, 284*(5411), 107-109.

Atkinson, P., & Hammersley, M. (1994). Ethnography and Participant Observation. In N. K. Denzin & Y. S. Lincoln (Eds.), *Handbook of Qualitative Research* (pp. 248-260). Thousand Oaks, CA: Sage.

Bailey, G. D. (1992). Wanted: A road map for understanding integrated learning systems. *Educational Technology, 32*(9), 3-5.

Bailey, K. D. (1987). *Methods of social research* (3rd ed.). New York: Macmillan.

Baker, E. L., Hermann, J. L., & Gearhart, M. (1996). Does technology work in schools? Why evaluation cannot tell the full story. In C. Fisher, D. C. Dwyer & K. Yocam (Eds.), *Education and technology: Reflections on computing in classrooms* (pp. 185-202). San Francisco: Jossey Bass.

Becker, H. J. (2000). Who's wired and who's not: Children's access to and use of computer technology. *The Future of Children, 10*(2), 44-75.

Becker, H. J., & Ravitz, J. L. (1999). The influence of computer and internet use on teachers' pedagogical practices and perceptions. *Journal of Research on Computing in Education, 31*(4), 356-384.

Beichner, R. J. (1993). Technology competencies for new teachers: Issues and suggestions. *Journal of Computing in Teacher Education, 9*(3), 17-20.

Bell, R. L., & Trundle, K. C. (2005). *The sky's the limit: The impact of planetarium software on preservice teachers' conceptions of moon phases.* Paper presented at the Association for the Education of Teachers of Science Annual Meeting, Colorado Springs, CO.

Bloom, J. W. (2001, April 2001). *Chaotic and complex systems in children's thinking and learning.* Paper presented at the American Educational Research Association Annual Meeting, Seattle, WA.

Bogdan, R. C., & Biklen, S. K. (1992). *Qualitative research for education: An introduction to theory and methods* (2nd ed.). Boston, MA: Allyn & Bacon.

Brand, G. A. (1998). What research says: Training teachers for using technology. *Journal of Staff Development, 19*(1), 10-13.

Bransford, J. D., Brown, A. L., & Cocking, R. R. (Eds.). (2000). *How people learn: Brain, mind, experience, and school.* Washington, DC: National Academy Press.

Brodnick, R. J. J., & Krafft, L. J. (1997, May 18-21,1997). *Chaos and complexity theory: Implications for research and planning in higher education.* Paper presented at the Association for Institutional Research Thirty-seventh Annual Forum, Orlando, FL.

Brown, A. L. (1992). Design experiments: Theoretical and methodological challenges in creating complex interventions in classroom settings. *The Journal of the Learning Sciences, 2*(2), 141-178.

Browne, D. L., & Ritchie, D. C. (1991). Cognitive apprenticeship: A model of staff development for implementing technology in schools. *Contemporary Education, 63*(1), 28-33.

Capra, F. (1996). *The Web of Life*. New York: Anchor Books.

Casti, J. L. (1994). *Complexification: Explaining a paradoxical world through the science of surprise*. New York: HarperPerennial.

Cohen, L., Manion, L., & Morrison, K. (2000). *Research methods in education* (5th ed.). New York: Routledge Farmer.

Collins, S. (2002). *The complexity of a participatory democracy in a public primary classroom: The interplay of student autonomy and responsibility.* Unpublished PhD dissertation, University of British Columbia, Vancouver, BC.

Conklin, H. (1968). Ethnography. In D. L. Sills (Ed.), *International encyclopedia of social sciences* (Vol. 5, pp. 115-208). New York: Free Press.

Creswell, J. W. (1998). *Qualitative inquiry and research design: Choosing among five traditions*. Thousand Oaks, CA: Sage.

Creswell, J. W. (2003). *Research design: Qualitative, quantitative, and mixed methods approaches* (2nd ed.). Thousand Oaks, CA: Sage.

Cuban, L. (1986). *Teachers and machines: The classroom use of technology since 1920*. New York: Teachers College Press.

Cuban, L. (1993). *How teachers taught: Constancy and Change in American Classrooms 1890-1990* (2nd ed.). New York: Teachers College Press.

Cuban, L. (1998). High-tech schools and low-tech teaching. *Journal of Computing in Teacher Education, 14*(2), 6-7.

Cuban, L. (2001). *Oversold and underused: Computers in the classroom*. Cambridge, MA: Harvard University Press.

Culp, K. M., Hawkins, J., & Honey, M. (1999). *Review paper on educational technology research and development*: Center for Children and Technology.

David, J. L. (1996). Developing and spreading accomplished teaching: Policy lessons from a unique partnership. In C. Fisher, D. C. Dwyer & K. Yocam (Eds.), *Education and technology: Reflections on computing in classrooms* (pp. 237-250). San Francisco: Jossey Bass.

Davies, P. (1988). *The cosmic blueprint: New discoveries in nature's creative ability to order the universe*. New York: Simon & Schuster.

Davis, B. (2006). Complexity and education: Some vital simultaneities: University of Alberta.

Davis, B., & Simmt, E. (2003). Understanding learning systems: Mathematics education and complexity science. *Journal for Research in Mathematics Education, 34*(2), 137-167.

Davis, B., & Simmt, E. (2006). Mathematics for teaching: An ongoing investigation of the mathematics that teachers (need to) know. *Educational Studies in Mathematics, 61*(3), 293-319.

Davis, B., Sumara, D., & Luce-Kapler, R. (2000). *Engaging minds: Learning and teaching in a complex world.* Mahwah, NJ: Lawrence Erlbaum.

Davis, B., & Sumara, D. J. (1997). Cognition, complexity, and teacher education. *Harvard Educational Review, 67*(1), 105-125.

Davis, B., & Sumara, D. J. (2000). Curriculum forms: On the assumed shapes of knowing and knowledge. *Journal of Curriculum Studies, 32*(6), 821-845.

de la Luna, L., & Kamberelis, G. (1997). *Refracted discourses/disrupted practices: Possibilities and challenges of collaborative action research in classrooms.* Paper presented at the National Reading Conference, Scottsdale, AZ.

Denzin, N. K., & Lincoln, Y. S. (Eds.). (1994). *Handbook of qualitative research.* Thousand Oaks, CA: Sage.

DeWalt, K. M., & DeWalt, B. R. (2002). *Participant observation: A guide for fieldworkers.* Walnut Creek, CA: Altamira Press.

Dexter, S. L., Anderson, R. E., & Becker, H. J. (1999). Teachers' views of computers as catalysts for changes in their teaching practice. *Journal of Research on Computing in Education, 31*(3), 221-239.

Doolittle, P. E. (2001). Complex constructivism: A theoretical model of complexity and cognition. Retrieved February 1, 2005, from http://edpsychserver.ed.vt.edu/research/complex1.html

DuFour, R., Eaker, R., & DuFour, R. (2005). Closing the knowing-doing gap. In R. DuFour, R. Eaker & R. DuFour (Eds.), *On common ground: The power of professional learning communities* (pp. 225-254). Bloomington, IN: National Educational Service.

Dutt-Doner, K., Wilmer, M., Stevens, C., & Hartmann, L. (2000). Actively engaging learners in interdisciplinary curriculum through integration of technology. *Computers in the Schools, 16*(3/4), 151-166.

Dwyer, D. C. (1996). The imperative to change our schools. In C. Fisher, D. C. Dwyer & K. Yocam (Eds.), *Education and technology: Reflections on computing in classrooms* (pp. 15-33). San Francisco: Jossey-Bass.

Dwyer, D. C., Ringstaff, C., & Sandholtz, J. H. (1991). Changes in teachers' beliefs and practices in technology-rich classrooms. *Educational Leadership, 48*(8), 45-52.

Edelson, D. C. (1998). Realising authentic science learning through adaptation of scientific practice. In B. J. Fraser & K. G. Tobin (Eds.), *International handbook of science education* (pp. 317-332). The Netherlands: Kluwer.

Ertmer, P. A., Gopalakrishnan, S., & Ross, E. M. (2001). Technology-Using Teachers: Comparing Perceptions of Exemplary Technology Use to Best Practice [Electronic Version]. *Journal of Research on Technology in Education*, 33. Retrieved May 22, 2006 from http://www.iste.org/Content/NavigationMenu/Publications/JRTE/Issues/Volume_331/Number_5_Summer_2001/jrce-33-5-ertmer.pdf.

Ertmer, P. A., & Hruskocy, C. (1999). Impacts of a University-Elementary School Partnership Designed to Support Technology Integration. *Educational Technology Research and Development, 47*(1), 81-96.

Evans, R. (2001). *The human side of school change: Reform, resistance, and the real-life problems of innovation.* San Francisco: Jossey-Bass.

Florio-Ruane, S. (2002). More light: An argument for complexity in studies of teaching and teacher education. *Journal of Teacher Education, 53*(3), 205-215.

Franklin, C. A., & Sessoms, D. B. (2006). *A Situative Perspective on a Collaborative Model for Integrating Technology into Teaching.* Paper presented at the American Educational Research Association Annual Conference, San Francisco.

Gallagher, R., & Appenzeller, T. (1999). Beyond reductionism. *Science, 284*(5411), 79-80.

Ginsberg, R. (1997). Complexity science at the schoolhouse gate? A call to arms! *Complexity, 2*(4), 9-13.

Glesne, C. (1999). *Becoming qualitative researchers: An introduction* (2nd ed.). New York: Longman.

Gold, R. (1958). Roles in sociological field observations. *Social Forces, 36*, 217-223.

Goldenfeld, N., & Kadanoff. (1999). Simple lessons from complexity. *Science, 284*(5411), 87-89.

Goldman-Segall, R. (1998). *Points of viewing children's thinking.* Mahwah, NJ: Lawrence Erlbaum.

Goodlad, J. (1988). School-university partnerships for educational renewal: Rationale and concepts. In K. A. Sirotnik & J. I. Goodlad (Eds.), *School-university partnerships in action: Concepts, cases, and concerns* (pp. 3-31). New York: Teachers College Press.

Gordon, D. T. (Ed.). (2000). *The digital classroom.* Cambridge, MA: Harvard Education Letter.

Guskey, T., & Huberman, M. (Eds.). (1995). *Professional development in education.* New York: Teachers College Press.

Haertel, G. D., & Means, B. (Eds.). (2003). *Evaluating educational technology: Effective research designs for improving learning.* New York: Teachers College Press.

Hawkins, J. (1996). Dilemmas. In C. Fisher, D. C. Dwyer & K. Yocam (Eds.), *Education and technology: Reflections on computing in classrooms* (pp. 35-50). San Francisco: Jossey-Bass.

Hitchcock, G., & Hughes, D. (1995). *Research and the teacher* (2nd ed.). London: Routledge.

Honey, M., & Moeller, B. (1990). *Teachers' beliefs and technology integration: Different values, different understandings (Technical Report 6)* (Technical Report). New York: Center for Children and Technology.

Horgan, J. (1995). From complexity to perplexity. *Scientific American, 272*(6), 104-109.

Horowitz, R. (1986). Remaining an outsider: Membership as a threat to research rapport. *Urban Life, 14*(4), 409-430.

Iannone, R. (1995). Chaos theory and its implications for curriculum and teaching. *Education 115*(4), 541-546.

International Society for Technology in Education. (2000). *National educational technology standards for students: Connecting curriculum and technology*. Eugene, OR: Author.

International Society for Technology in Education. (2002). *National educational technology standards for teachers: Preparing teachers to use technology*. Eugene, OR: Author.

ISTE Members Impact Positive EETT Vote [Electronic (2006). Version]. Retrieved July 22, 2006 from http://www.iste.org/Template.cfm?Section=Home&Template=/ContentManagement/ContentDisplay.cfm&ContentID=13512.

Johnson, S. (2001). *Emergence: The connected lives of ants, brains, cities, and software*. New York: Scribner.

Jonassen, D. H. (2000). *Computers as mindtools for schools: Engaging critical thinking* (2 ed.). Upper Saddle River, NJ: Merrill.

Jonassen, D. H., Carr, C., & Yueh, H.-P. (1998). Computers as mindtools for engaging learners in critical thinking. *Techtrends, 43*(2), 24-32.

Jonassen, D. H., Howland, J., Moore, J., & Marra, R. M. (2003). *Learning to solve problems with technology: A constructivist perspective* (2nd ed.). Upper Saddle River, NJ: Merrill Prentice Hall.

Jörg, T. (2000). About the unexpected complexity of learning based on reciprocity and human agency. *Chaos and complexity theory: Special interest newsletter* Retrieved February 3, 2005, from http://www.udel.edu/aeracc/library/Fall00.htm

Jorgenson, D. L. (1989). *Participant observation: A methodology for human studies* (Vol. 15). Newbury Park, CA: Sage.

Kauffman, S. (1995). *At home in the universe: The search for the laws of self-organization and complexity*. New York: Oxford University Press.

Kelso, J. A. S. (1995). *Dynamic patterns: The self-organization of brain and behavior.* Boston: MIT Press.

Killion, J. (1999). *What works in the middle: Results-based staff development.* Oxford, OH: National Staff Development Council.

Kimmel, H., & Deek, F. E. (1995). Instructional technology: A tool or a panacea? *Journal of Science Education and Technology, 4*(4), 327-332.

Kulik, C. L. C., & Kulik, J. A. (1991). Effectiveness of computer-based instruction: An updated analysis. *Computers in Human Behavior, 7*, 75-94.

Kulik, J. A. (2003). *Effects of using instructional technology in elementary and secondary schools: What controlled evaluation studies say* (No. P10446.001). Arlington, VA: SRI International.

Laidlaw, L. (2004). On the importance of little details: Complexity, emergence and pedagogy [Electronic Version]. *Educational Insights*, 9, 1-13. Retrieved January 29, 2005 from http://www.ccfi.educ.ubc.ca/publication/insights/v09n01/articles/laidlaw.html.

Laurier, E. (2003). Participant-observation. Retrieved April 30, 2003, from http://www.geog.gla.ac.uk/~elaurier/texts/PART-OB.pfd

Lesgold, A. (2003). Detecting technology's effects in complex school environments. In G. D. Haertel & B. Means (Eds.), *Evaluating educational technology : Effective research designs for improving learning* (pp. 38-74). New York: Teachers College Press.

Lewin, R. (1999). *Complexity: Life at the edge of chaos* (2nd ed.). Chicago, IL: University of Chicago Press.

Lincoln, Y. S., & Guba, E. G. (1985). *Naturalistic Inquiry.* Beverly Hills, CA: Sage.

Linn, M. C., Davis, E. A., & Bell, P. (Eds.). (2004). *Internet environments for science education.* Mahwah, NJ: Lawrence Erlbaum Associates.

Mann, D. (1999). *Documenting the effects of instructional technology: A flyover of policy questions.* Paper presented at the Secretary's Conference on Educational Technology: 1999.

Marshall, C., & Rossman, G. B. (1999). *Designing qualitative research* (3rd ed.). Thousand Oaks, CA: Sage.

Marx, R. W., Blumenfeld, P., Krajcik, J., & Soloway, E. (1997). Enacting project-based science. *The Elementary School Journal, 97*(4), 341-358.

Mayer-Smith, J. A., Pedretti, E. G., & Woodrow, J. E. J. (1998a). An examination of how science teachers' experiences in a culture of collaboration inform technology implementation. *Journal of Science Education and Technology, 7*(2), 127-134.

Mayer-Smith, J. A., Pedretti, E. G., & Woodrow, J. E. J. (1998b). Embracing technology to improve science teaching and learning. *Journal of Staff Development, 19*(1), 26-31.

McAndrew, D. A. (1997). Chaos, complexity, and fuzziness: Science looks at teaching English. *English Journal, 86*(7), 37-43.

McCabe, M., & Skinner, R. A. (2003). Analyzing the tech effect. *Education Week's Technology Counts 2003, 22*(35), 50-52.

McQuinn, C., & Roach, M. (1998). The Writing Process: A Web Tutorial.

Means, B. (1994). *Technology and education reform: The reality behind the promise.* San Francisco: Jossey bass.

Means, B., Haertel, G. D., & Moses, L. (2003). Evaluating the effects of learning technologies. In G. D. Haertel & B. Means (Eds.), *Evaluating educational technology: Effective research designs for improving learning* (pp. 1-13). New York: Teachers College Press.

Mehlinger, H. D. (1997). The next step [Electronic Version]. *Electronic School.* Retrieved August 28, 2006 from http://www.electronic-school.com/0697f2.html.

Merriam, S. B. (1998). *Qualitative Research and Case Study Applications in Education.* San Francisco: Jossey-Bass.

Minstrell, J. (1996). A classroom environment for learning: Guiding students' reconstruction of understanding and reasoning. In L. Schauble & R. Glaser (Eds.), *Innovations in learning: New environments for education.* Mahwah, NJ: Erlbaum.

Mistler-Jackson, M., & Songer, N. B. (2000). Student motivation and internet technology: Are students empowered to learn science? *Journal of Research in Science teaching, 37*(5), 459-479.

Morowitz, H. J. (2002). *The emergence of everything: How the world became complex.* New York: Oxford University Press.

National Research Council. (1996). *National science education standards.* Washington, DC: National Academy Press.

National Staff Development Council. (2001). *Standards for staff development (revised).* Oxford, OH: National Staff Development Council.

O'Dwyer, L. M., Russell, M., & Bebell, D. J. (2004). Identifying teacher, school, and district characteristics associated with elementary teachers' use of technology: A multilevel perspective. *Education Policy Analysis Archives, 12*(48).

Papert, S. (1980). *Mindstorms: Children, computers, and powerful ideas.* New York: Basic Books.

Patton, M. Q. (2002). *Qualitative research and evaluation methods* (3rd ed.). Thousand Oaks, CA: Sage.

Pedretti, E., Mayer-Smith, J., & Woodrow, J. (1998). Technology, text, and talk: Students' perspectives on teaching and learning in a technology-enhanced secondary science classroom. *Science Education, 82*, 569-589.

Pedretti, E. G., Mayer-Smith, J. A., & Woodrow, J. E. J. (1998). Technology, text, and talk: Students' perspectives on teaching and learning in a technology-enhanced secondary science classroom. *Science Education, 82*, 569-589.

Pedretti, E. G., Mayer-Smith, J. A., & Woodrow, J. E. J. (1999). Teaming Technology Enhanced Instruction in the Science Classroom and Teacher Professional Development. *Journal of Technology and Teacher Education, 7*(2), 131-143.

Phelps, R., & Hase, S. (2002). Complexity and action research: Exploring the theoretical and methodological connections. *Educational Action Research, 10*(3), 507-523.

Pigliucci, M. (2000). Chaos and complexity: Should we be skeptical? *Skeptic, 8*(3), 62-70.

Reason, P., & Goodwin, B. (1999). Toward a science of qualities in organizations: Lessons from complexity theory and postmodern biology. *Concepts and Transformation, 4*(3), 281-317.

Reeves, T. C. (1998). *The impact of media and technology in schools: A research report prepared for the Bertelsmann Foundation*: The University of Georgia.

Reilly, B. (1996). New technologies, new literacies, new problems. In C. Fisher, D. C. Dwyer & K. Yocam (Eds.), *Education and technology: Reflections on computing in classrooms* (pp. 203-220). San Francisco: Jossey Bass.

Ringstaff, C., & Kelley, L. (2002). *The learning return on our educational technology investment*. San Francisco: WestEd.

Roschelle, J. M., Pea, R. D., Hoadley, C. M., Gordin, D. N., & Means, B. (2000). Changing how and what children learn in school with computer-based technologies. *The Future of Children, 10*(2), 76-101.

Rule, A. C., Barrera, M. T., III, Dockstader, C. J., & Derr, J. A. (2002). Comparing Technology Skill Development in Computer Lab versus Classroom Settings of Two Sixth Grade Classes [Electronic Version]. *Journal of Interactive Online Learning*, 1. Retrieved July 22, 2006 from http://www.ncolr.org/jiol/issues/showissue.cfm?volID=1&IssueID=2.

Salomon, G. (1990). The computer lab: A bad idea now sanctified. *Educational Technology, 30*(10), 50-52.

Salomon, G. (2000, June 28, 2000). *It's not just the tool, but the educational rationale that counts.* Paper presented at the Ed-Media, Montreal, Quebec, Canada.

Salomon, G., Perkins, D. N., & Globerson, T. (1991). Partners in cognition: Extending human intelligence with intelligent technologies. *Educational Researcher, 20*(3), 2-9.

Sandholtz, J. H., & Ringstaff, C. (1996). Teacher change in technology-rich classrooms. In C. Fisher, D. C. Dwyer & K. Yocam (Eds.), *Education and technology: Reflections on computing in classrooms* (pp. 281-299). San Francisco: Jossey Bass.

Sandholtz, J. H., Ringstaff, C., & Dwyer, D. C. (1997). *Teaching with technology: Creating student-centered classrooms*. New York: Teachers College Press.

Schacter, J., & Fagnano, C. (1999). Does computer technology improve student learning and achievement? How, when, and under what conditions? *Journal of Educational Computing Research, 20*(4), 329-343.

Schrum, L. (1999). Technology Professional Development for Teachers. *Educational Technology Research and Development, 47*(4), 83-90.

Seidman, I. (1998). *Interviewing as qualitative research: A guide for researchers in education and the social sciences* (2nd ed.). New York: Teachers College Press.

Shields, M. K., & Behrman, R. E. (2000). Children and computer technology: Analysis and recommendations. *The Future of Children, 10*(2), 4-30.

SIIA. (2000). *2000 research report on the effectiveness of technology in schools: Executive summary*: Software and Information Industry Association.

Smith, M. S., & Broom, M. (2003). The landscape and future of the use of technology in K-12 education. In H. F. O'Neil & R. S. Perez (Eds.), *Technology applications in education: A learning view* (pp. 3-30). Mahwah, NJ: Lawrence Erlbaum.

Sparks, D. (1998). Using Technology to Improve Teaching and Staff Development: An Interview with Kathleen Fulton. *Journal of Staff Development, 19*(1), 18-21.

Spradley, J. P. (1980). *Participant Observation*. New Haven, CT: Thomson Learning.

Stake, R. E. (1995). *The art of case study research*. Thousand Oaks, CA: Sage.

StarLogo on the Web. Retrieved March 5, 2006, from http://education.mit.edu/starlogo/

Sumara, D. J., & Davis, B. (1997). Enlarging the space of the possible: Complexity, complicity, and action-research practices. In T. R. Carson & D. J. Sumara (Eds.), *Action research as a living practice* (Vol. 67, pp. 299-312). New York: Peter Lang.

Technology Counts (2003). *Pencils down: Technology's answer to testing* Retrieved July 2, 2006, from http://counts.edweek.org/sreports/tc03/

Technology Counts [Electronic (2006). Version]. *Education Week*, 25. Retrieved July 22, 2006 from http://www.edweek.org/ew/toc/2006/05/04/index.html.

Thelen, E., & Smith, L. B. (1994). *A dynamic systems approach to the development of cognition and action.* Cambridge, MA: MIT Press.

Thornburg, D. D. (2000a). *Renaissance 2000*: The Thornburg Center.

Thornburg, D. D. (2000b). *Technology in K-12 education: Envisioning a new future.* Paper presented at the Forum on the future of technology in education.

Thurlow, J. P. (1999, May 2-7, 1999). *Teachers as technologists: Professional development for technology integration.* Paper presented at the 44th Annual Meeting of the International Reading Association, San Diego, CA.

Tierney, R. J. (1996). Redefining computer appropriation: A five-year study of ACOT. In C. Fisher, D. C. Dwyer & K. Yocam (Eds.), *Education and technology: Reflections on computing in classrooms* (pp. 169-183). San Francisco: Jossey Bass.

Trundle, K. C., & Bell, R. L. (2005). *The use of computer simulation to promote scientific conceptions of moon phases.* Paper presented at the National Association for Research in Science Teaching, Dallas, TX.

Tyack, D., & Cuban, L. (1995). *Tinkering towards Utopia: A century of public school reform.* Cambridge, MA: Harvard University Press.

Varela, F. J., Thompson, E., & Rosch, E. (1991). *The embodied mind: Cognitive science and human experience.* Cambridge, MA: MIT Press.

Waldrop, M. M. (1992). *Complexity: The emerging science at the edge of order and chaos.* New York: Simon & Schuster.

Wartella, E. A., & Jennings, N. (2000). Children and computers: New technology - old concerns. *The Future of Children, 10*(2), 31-43.

Watson, D. M. (1990). The Classroom vs the Computer Room. *Computers and Education, 15*(1), 33-37.

Waxman, H. C., Connell, M. L., & Gray, J. (2002). *A quantitative synthesis of recent research on the effects of teaching and learning with technology on student outcomes*. Naperville, IL: North Central Regional Educational Laboratory.

Weaver, W. (1948). Science and complexity. *American Scientist, 36*, 536-544.

Wenger, E. (1998). *Communities of practice: Learning, meaning, and identity*. New York: Cambridge University Press.

Wenglinsky, H. (1998). *Does it compute? The relationship between educational technology and student achievement in mathematics*. Princeton, NJ: Educational Testing Service.

Wolcott, H. F. (2002). Ethnography? Or educational travel writing? In Y. Zou & E. T. Trueba (Eds.), *Ethnography and schools: Qualitative approaches to the study of education* (pp. 27-48). Lanham, MD: Rowman & Littlefield.

Woodrow, J. E. J., Mayer-Smith, J. A., & Pedretti, E. G. (1996). The impact of technology enhanced science instruction on pedagogical beliefs and practices. *Journal of Science Education and Technology, 5*(3), 241-252.

Woodrow, J. E. J., Mayer-Smith, J. A., & Pedretti, E. G. (2000). Assessing technology enhanced instruction: A case study in secondary science. *Journal of Educational Computing Research, 23*(1), 15-39.

Yin, R. K. (1994). *Case Study Research: Design and Methods* (2nd ed.). Thousand Oaks, CA: Sage.

Zhao, Y., Pugh, K., Sheldon, S., & Byers, J. L. (2002). Conditions for classroom technology innovation. *Teachers College Record, 104*(3), 482-515.

Appendices

Appendix A: Teacher Interview Questions

Interviews were conducted with the classroom teacher approximately once each month for the duration of the project. The interviews were semi-structured, allowing the participant to provide some direction to the conversation regarding her teaching and use of technology in the classroom.

- Describe your current use of technology (school and personal)
- How have you learned to use technology? Has that changed over time?
- What is the best role for technology in your classroom?
- Do you think that technology is a useful tool for enhancing student learning? If so, in what ways? Can you give evidence?
- In what ways have you used technology to enhance your science instruction?
- Is technology more appropriate in particular curriculum areas than others?
- Do you think technology can take the place of other means of instruction, or is it better used as a supplement?
- Do you think there are good resources about technology available? If so, what are they?
- How would you define a good technology resource?
- What kind of support do you feel is necessary for you as you learn new ways of teaching? Do you feel that you get that support?
- Do you see yourself as someone who adapts to change easily? Why? Why not?

Appendix B: Student Interview Questions

Interviews were conducted with each student, towards the end of the project. These interviews were semi-structured, allowing the student to provide some direction to the conversation regarding learning and the use of computers.

- How do you use computers at home and at school?
- Do you like using computers? At home? At school?
- Do you think computers are helpful to you when you're learning? Why, or why not?
- How do you learn best?
- Do you think that using computers in our classroom over the last few months for science has helped you learn? Why, or why not?
- Would you rather learn with computers, or without them?

MacIntosh Windows Other Don't know

7. If you circled Yes in #5, does your home computer have Internet access? (Circle one)
   Yes No

8. If you have a computer at home, do you use it for (Circle all that fit):
   School work Games E-mail Chat Rooms Fun Research
   Other____

9. How often do you use a computer at home? (Circle one)
   Every day Every other day Once a week Twice a month
   Once a month Never

10. What do you think computers are most useful for?
    ____
    ____
    ____
    ____
    ____
    ____

11. When did you start using computers at school? (Circle one)
    Before kindergarten Kindergarten 1^{st} grade 2^{nd} grade 3^{rd} grade 4^{th} grade

12. How often do you use the computer at school? (Circle one)
    Every day Every other day Once a week Twice a month
    Once a month Never

10. What do you think computers are most useful for?

____
____
____
____
____
____

11. When did you start using computers at school? (Circle one)
Before kindergarten Kindergarten 1st grade 2nd grade 3rd grade 4th grade

12. How often do you use the computer at school? (Circle one)
Every day Every other day Once a week Twice a month
Once a month Never

13. Do you use the computer more or less now than you did at the beginning of the school year? (Circle one)
More Less Same

14. Do you feel more or less comfortable now using the computer than you did at the beginning of the school year? (Circle one)
More Less Same

Why do you think that is?

____
____
____
____
____
____

15. Are there any other comments you'd like to make about computers?

____
____
____
____
____
____
____
____
____

Thank you for taking this survey!

Appendix E: Space Exploration Timeline

EVENT	DATE
Moon Landing	**March 16, 1926**
First American Out of Capsule Spacewalk (Extravehicular Activity-EVA)	**January 31, 1958**
Goddard Rocket	**May 1961-May 1963**
Space Shuttle Program	**March 1965-November 1966**
Gemini Program	**June 3, 1965**
Skylab Missions	**January 1967-December 1972**
Apollo Program	**July 20, 1969**
Explorer I	**May 1973-February 1974**
Mercury Program	**July 15-24, 1975**
Apollo-Soyuz Test Project	**April 1981-Present**
First American Woman in Space	**June 18, 1983**

Do some research to MATCH the space events above with the date they occurred. Then, cut out BOTH the event and the date and place them on your *Space Exploration Timeline.*

Telescope Time Chart

1608	**Telescope is invented**
1610	**Galileo makes a telescope for use with his astronomy experiments**
1668	**Sir Isaac Newton makes the first reflecting telescope**
1781	**Sir William Herschel discovers Uranus and measures the length of a day on Mars**
1824	**First telescope is fitted with a clockwork motor so it can follow the motion of the stars**
1845	**A 36 inch reflector discovers the spiral shape of galaxies**
1937	**The first radio telescope is built**
1962	**The first orbiting laboratory is launched**
1990	**Hubble Space Telescope is launched**

The telescope events above are already matched to their dates. Cut them out and add them to your *Space Exploration Timeline*.

Space Probe Schedule

1965	**Mariner space probe photographs Mars.**
1975	**Venera 9 and 10 land on Venus, taking pictures before being burned up by the poisonous atmosphere. Venera was a Russian space probe.**
1976	**Viking 1 and 2 orbit Mars. Landers are sent to the Martian surface.**
1977	**Voyager spacecraft launched to study the outer planets.**
1989	**Magellan launched from the space shuttle Atlantis.**
1995	**Galileo probe reaches Jupiter.**
1997	**Mars Pathfinder lands on Mars.**

These space probe events are already matched to their dates. Cut these out and add them to your *Space Exploration Timeline*.

When you are completely finished with placing all events on your timeline, choose one that interests you and do some more research about it!