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DEVELOPMENT OF AN ELEMENTARY SCIENCE CURRICULUM BASED ON MODERN ASTROBIOLOGY TO ASSESS THE EFFECTIVENESS OF COMPUTER TECHNOLOGY ON LEARNING

by

Thomas Harttung Nassif

submitted to the
Faculty of the College of Arts and Sciences
of American University
in Partial fulfillment of
the Requirements for the Degree of
Master of Science
in
Biology

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ABSTRACT

A science curriculum was created to enhance student awareness of Astrobiological research and to assess the effectiveness of computers on learning. Three curricular units (water, microscopic life, hydrothermal vents) emphasize life's origins and the potential existence of life beyond Earth.

This study assessed the academic benefits of computers among Grade 4 students (n=49). The curricular material between test (computer use) and control groups differed only in student use of computers (Internet, Excel, Kid Pix, and Powerpoint) for activities. All students' scores improved from pre- to posttest (t=17.4, p=0). Posttest scores did not differ between groups (t=0.54, p=0.59), suggesting the assessments' inability to detect student computer skills and the variability in usefulness of different computer applications. Take-home projects involving Internet research resulted in higher scores among test group students (t=2.7, p=0.01). Test group students were on par with the control group for every assessment, and developed valuable skills in the process.

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SCIENCE EDUCATION AND COMPUTER TECHNOLOGY

Introduction

Science education is vital to building a scientifically literate citizenry that will react intelligently and responsibly to the unfolding discoveries that inevitably influence our daily lives. One rapidly expanding field is astrobiology, a scientific discipline devoted to the study of life on Earth and the search for life elsewhere in the universe. Astrobiologists explore the planet upon which we live and the farthest reaches of the solar system to learn more about the origin of life and the potential for life to exist beyond Earth. I created a Grade 4 science curriculum based upon three central tenants of current astrobiological research (water, microscopic life, and hydrothermal vents) to assess the effectiveness of computer technology on learning. Few studies have investigated quantitatively the academic benefits of computer technology despite the rapid advancements in technology and increased presence in schools. If computers are to become increasingly central to academic settings, it is imperative that more studies investigate and explore the most effective methods for teaching science.

Science Education in the U.S.

By the start of the 20th century, most U.S. schools embraced the need for science instruction, a discipline that had often been absent from school curricula at the expense of the humanities. Most educators believed that science would serve as a vehicle for making education more socially relevant and more focused on independent thought. John Dewey (1998) concurred in asserting "the scientific method is the only authentic means at our command for getting at the significance of our everyday experiences of the world in which we live."

The goals and motives for teaching science in the U.S. radically changed in response to WWII and the subsequent launching of Sputnik. By 1957, "the schools were made the scapegoat for the U.S. failure in the race for space" (Sadker and Sadker, 2000). The spirit of independent thought that had formerly characterized science education was replaced by a sudden interest "in the strategic role of scientific knowledge in society" (DeBoer, 2000). Millions in federal funds were spent on recruiting scientists to develop curricula that were laboratory-based and appreciative of the way scientists carried out their work (Esler and Esler, 1993). Yet "despite the best intentions of the high powered curriculum development efforts of the 1960's, there is little evidence...that classroom practice actually changed as a result of exposure to high quality curriculum materials" (Hart and Robottom, 1990).

The unprecedented involvement of the federal government and scientific community in developing school science programs in the 1950's and 60's significantly impacted the future of science education. Many argued that the science programs were too restrictive and too "focused on teaching abstract models of the natural world that had been organized by scientists" (DeBoer, 2000). One program, Science – A Process Approach (SAPA), featured basic skills scientists used but placed little emphasis on teaching scientific concepts (Esler and Esler, 1993). Today it is generally agreed that effective science curricula are balanced in substantive content and relevant process skills. "Scientific literacy has been achieved when a person is able and willing to continue to learn science content [and] to develop science processes." (Sutman, 1996).

The science programs of the 1950's and 60's took a dramatic departure from John Dewey's vision of science education thirty years earlier. Many criticized the paucity of scientific applications to the daily experiences of students. In 1959, Jerome Bruner asserted "teaching specific topics or skills without making clear their context…is uneconomical" (Bruner, 1960). By 1971, the National Science Teachers Association emphasized "science and society" as the most important goal of science education and asserted that students should be taught "scientific concepts, process skills, and values in making everyday decisions" (DeBoer, 2000). Today, most educators concur that learning science in a socially relevant context is "the most direct avenue to understanding of science itself" (Dewey, 1998).

The 1990's brought about a new wave of reform aimed at empowering teachers to structure their own curricula while maintaining accountability for student learning. The initial push for reform was triggered by *A Nation at Risk*, a political report published in 1983 highlighting the declining test scores of American youth in math and science (DeBoer, 2000). Many lawmakers and educators proposed that a set of standards be created for every discipline and grade level. In this way, teachers would be held accountable for the academic achievement of their students. The American Association for the Advancement of Science (AAAS) created a set of science standards in 1993 to clarify the goals of science education. Science educators from across the country agreed upon a set of concepts called "benchmarks" that students should comprehend by the time they reach a certain grade level (AAAS, 1993). Standards-based reform "describes an educational system…in which teachers are empowered to make decisions essential for effective learning" (NRC, 1996). Public school systems throughout the nation would eventually adopt their own version of science standards, while independent schools would tend to rely on the Benchmarks. The success of standards-based reform in science education is difficult to assess. The TIMSS-R, an international math and science test administered to students in Grades 4 and 8, last year ranked the United States 18th in science and 19th in math out of 38 competing nations. Many affluent districts tended to be on par with the top scoring nations internationally while many urban school districts such as Washington, D.C. were outperformed by 36 nations (*Washington Post*, 28 January 2001). With such a wide range in scores it is difficult to determine the success of standards-based reform in science education.

The Effectiveness of Computer Technology on Science Instruction

A small number of existing studies suggest that computer technology improves academic achievement. "Large-scale, statewide implementations of educational technology" such as those in West Virginia and Idaho have resulted in significant gains in standardized test scores (Sivin-Kachala and Bialo, 2000). Data from the 1996 National Assessment of Educational Progress (NAEP) in mathematics were analyzed to determine if the frequency of computer use in schools impacted student academic achievement. Harold Wenglinsky (1998) found that among 6,227 fourth-graders "using computers for learning games was positively correlated to academic achievement" (Wenglinksy, 1998). Two other studies found similar results at the classroom level. Gardner, *et al.* (1992) conducted a study in which different instructional methods were used to teach third-graders meteorology concepts. The group exposed to software and hands-on activities out-performed those students receiving hands-on activities alone, or traditional instruction. Similarly, when the Kids Global Scientists program (KGS), an internet-based middle school science curricula, was administered to classrooms in suburban and inner-city areas, students in both environments displayed "statistically significant improvement on science content and inquiry" (Mistler-Jackson and Songer, 2000, 462). However, the absence of control groups in the study (group without computer exposure) prevented proper assessment of the effectiveness of the KGS software on student learning.

Results from other quantitative studies have failed to document a positive correlation. For example, Tobin (1999) detected no significant difference in posttest scores between seventh grade students exposed to computer-based instruction and students exposed to hands-on activities alone. However, the two curricula designed for use by the test group (computer use) and the control group in this study were not clearly described. In addition, Tobin did not administer pretests before each unit to ensure that the two groups represented two pools of equally knowledgeable students.

Numerous qualitative studies attest to the academic benefits of computer technology in the classroom, citing such positives as increased student motivation levels, and heightened enjoyment and interest towards the subject matter (Archer, 1998) (Pugalee and Robinson, 1998) (Schofield, 1995). Some researchers further assert that classroom computer use enables teachers to accomplish a constructivist approach towards learning, an approach whereby students actively build their knowledge from exposure to an information-rich environment (Becker and Ravitz, 1999) (Archer, 1998). Finally, other studies suggest that students who are visual learners will particularly benefit from the computer's ability to make things visual (Archer, 1998).

Many critics argue that computers bring little to the educational process, as they may potentially serve as a distraction or as poor substitutes for direct teacher-student interaction (Archer, 1998) (Healy, 2000). Other critics add that computer use in the classroom would "limit opportunities for social interaction, thus interfering with the learning process" (Wenglinsky, 1998). In addition, Jane Healy (2000) claims that software discourages students from thinking in reflective, creative, and deep ways. Research studies devoted to designing internet activities concur, finding that students spend little time attempting to understand or evaluate the information they retrieve, "but instead focus on finding quick answers and making shallow interpretations of information" (Mistler-Jackson and Songer, 2000). Even in the event computers do produce gains in academic achievement, critics assert that the benefits "are not proportionate to the costs of buying and maintaining computers" (Wenglinsky, 1998).

Proponents of computer use in schools assert that the skills students learn from computers are vital to their success in the future job market. "Recent projections claim that in just a few years, 60% of all jobs will require technological skills that only a fraction of Americans now have" (Mistler-Jackson and Songer, 2000, 459). Yet, Healy (2000) sees little use in spending large quantities of time on mouse skills and keyboarding. With technology changing so rapidly these skills will soon become obsolete; students should instead develop "good work habits, internally driven motivation, creativity, and imagination" (Healy, 2000).

The issue of whether to implement computer technology in schools goes far beyond analyzing the benefits and limitations of computers as isolated objects. Schofield (1995) contends "the view that computers [alone] will suddenly revolutionize education is most likely mistaken." Equally important to the presence of computers in the classroom is the instructional method teachers choose to teach their curricular ideas with the use of technology. "Evaluations of education technology are...highly dependent on the implementation of the instructional design" (Coley, 1997). Despite the finding that students benefit when computers are used to teach higher-order thinking skills (Archer, 1998), few teachers use computers to develop critical thinking skills in elementary school classrooms (Becker, 1994). Some studies have found inadequate teacher training to be an issue (Pugalee and Robinson, 1998, 79), and this may account for the reluctance of teachers to use computers for teaching higher-order thinking skills. For computers to become effective classroom tools, teachers must "create an environment where authentic activities are valued and students are given responsibility and autonomy for their own learning" (Pugalee and Robinson, 1998, 78).

Another issue of concern involves determining the age levels that benefit most from classroom computer use. The aforementioned study on the 1996 NAEP found "the effects of technology...to be much smaller in the fourth than the eighth grade" (Wenglinsky, 1998). These results suggest that all technology initiatives be primarily aimed towards middle schools, an assertion based upon the belief that most students are not introduced to higher order concepts before middle school (Wenglinsky, 1998). Conversely, two aforementioned studies conducted at the elementary level suggest that elementary students are capable of reaping the academic benefits from computer technology on learning science (Gardner, *et al*, 1992) (Mistler-Jackson and Songer 2000). Both studies assessed the use of computers to teach science content. Since Wenglinsky bases his argument on student math scores (NAEP), the effectiveness of computer use on science instruction is difficult to determine. The conflicting research on the usefulness of computer technology to education in general suggests that computers should be viewed as tools, and that their effectiveness is contingent on how they are used in the classroom. More quantitative research must be conducted to assess the effectiveness of computer technology on learning science and to determine the most effective methods for achieving these academic benefits in the elementary classroom.

CHAPTER 2

CURRICULUM OVERVIEW

Relevance to the Science Content Standards and Current Teaching Philosophies

A new Grade 4 science curriculum was created and implemented for this study to instill within students a rich understanding of current scientific research in Astrobiology. The structure and thematic arrangement of the Astrobiology curriculum illustrates how Grade 4 students may be taught to apply their knowledge of basic biological concepts to develop an appreciation of current research in areas such as Astrobiology. The curriculum consists of hands-on activities organized into three units: water, microscopic life, and hydrothermal vents (see Appendices 1, 2, and 3). The activities within each unit directly relate to the essential question of the curriculum "How did life begin on Earth and does life exist elsewhere in our Universe?" The curriculum addresses issues that have been vitally important to the evolution of science education. Effective science curricula are justified by science content standards, balanced among concepts and skills, and socially relevant.

The curriculum is sensitive to two sets of science content standards, the AAAS Benchmarks and the D.C. public school standards. The AAAS Benchmarks list specific age-appropriate concepts for four different grade levels (K-2, 3-5, 6-8, 9-12). The concepts for Grades 3-5 should be introduced in the third and fourth grades. By fifth grade, these concepts should become essential knowledge (AAAS, 1993). The first two columns of Table 1 lists activity topics within the curriculum and the AAAS benchmarks they address. In contrast to the benchmarks, the D.C. performance standards for science are divided by individual grade level (DCPS, 1999). Table 1 also provides the D.C. performance standards for Grade 4 addressed in the proposed curriculum.

The curriculum is balanced in concepts and process skills, both of which are necessary to achieve scientific literacy. The current trend in science teaching emphasizes constructivism: students should "actively construct, or build their own knowledge in a process that is individual and social" (Lowery, 1997, 7). Concepts placed in an organized framework (as in a curriculum) allow students to construct their knowledge while process skills enable them to apply this information to new situations. An example of the importance of concepts and skills to constructivist philosophy may be seen in the Depth Soundings activity (see Appendix 3). To understand such concepts as depth soundings and ocean floor features, students must employ their measurement skills (to measure different depths) and graphing skills (to translate their findings into a 3-D bar graph). Each activity within the curriculum addresses specific *concepts* and develops relevant *process skills* (Appendices 1, 2, and 3).

It is generally agreed among elementary educators that broad thematic units, which emphasize connections across disciplines, result in greater student understanding of concepts. "To slice knowledge into arbitrary and separated segments denies students a rich, textured, and coherent understanding" of the subject matter (Sadker and Sadker, 2000, 230). The proposed curriculum addresses concepts representative of the three

Table 1. The activity topics presented in the curriculum and the content standards they address.

Activity Topic	AAAS Benchmarks	D.C. Performance Standards
Properties of water	When liquid water disappears, it turns into a gas in the air and can reappear as a liquid when cooled.	Constructs a model of a water cycle to know that when liquid disappears, it turns into a gas (vapor) and can reappear as a liquid when cooled.
Microscopes and Importance of water to life	Microscopes make it possible to see that living things are made mostly of cells; Living things need food, water, and air.	Uses microscopes to know that some things consist of a single cell. Concludes that like familiar organisms, they need food, water, air.
Bacteria and Life at extremes	Most microorganisms do not cause disease, and many are beneficial.	Surveys the habitats and activities of microorganisms in their own environment to understand that most microorganisms do not cause disease, and many are beneficial.
Food webs and Hydrothermal vents	Almost all kinds of animals' food can be traced back to plants. Some source of energy is needed for all organisms to stay alive and grow.	Observes that organisms interact with one another in various ways. Observes the growth requirements of a variety of organisms.
Evolution of life on Earth	Some kinds of organisms that once lived on earth have completely disappeared, although they were something like others alive today.	Deduces over the whole earth, organisms are growing, dying and decaying, and new organisms are being produced by the old ones.

accepted elementary science disciplines: earth and space, physical, and life science. The prospect of finding life beyond Earth, the properties of water, and the life forms found at hydrothermal vents are examples of curriculum topics that respectively address these three scientific disciplines.

Social relevance in the science curriculum is essential to inspiring and capturing the curiosities of children. John Dewey (1998) concurs in asserting, "It is a sound educational principle that students should be introduced to scientific subject matter...through acquaintance with everyday social applications." An important goal of the proposed curriculum is to enhance student awareness of current scientific research in the field of astrobiology. By connecting exciting research findings to important scientific concepts (as prescribed in the science content standards), students will be more likely to support and lead exciting exploits into the frontiers of scientific research. The curriculum is centered upon Astrobiology, the study of life's origins on Earth and the search for life elsewhere in the Universe. The hands-on activities offer numerous opportunities to discuss current findings in Astrobiology.

Relevance to Current Research in Astrobiology

The curriculum underscores three age appropriate themes that enable Grade 4 students to fully appreciate and understand the significance of current research in astrobiology: 1) The importance of water to life; 2) The role of bacteria in evolution; and 3) The significance of hydrothermal vents to the origin of life. Researchers spanning many disciplines – from astronomy to molecular biology – work together as astrobiologists to unlock the mysteries behind life's origins on Earth and the potential for life to exist elsewhere in the universe. A knowledge of water, microscopic life, and hydrothermal vents enables astrobiologists to carry out their research, and likewise, enables students to comprehend this research.

Every example of life on Earth shares the need for water. The discovery of viable bacteria in the polar ice caps of Antarctica and in the hot acid springs of Yellowstone demonstrate life has few limits. The presence of frozen water on Mars coupled with evidence of a liquid ocean under the icy surface of Jupiter's moon Europa lead many researchers to believe life exists beyond our planet (Stevenson, 2000). "The growing awareness that there is hardly a potential habitat on Earth not harboring life…is now changing our consensus of consequences for life within the unfriendly habitats" of other planets and moons (Richmond, *et al*, 1999).

In addition to their popularity among scientists as candidates for extraterrestrial life, bacteria are thought to be the closest relatives to the first life on Earth (Davies, 1999). The earliest fossil evidence suggests that life began 3.8 billion years ago (Freeman, 1998). Scientists theorize that asteroids bombarded the Earth producing surface temperatures well above 800 C (Watanabe, 1999). The heat-loving bacteria discovered in extreme environments such as Yellowstone may be the remnants of a young, more violent Earth.

Beyond searching for the closest relatives to the first life forms on Earth, astrobiologists must infer *where* life began to subsequently form the immense diversity of life on Earth today. Charles Darwin believed life began in a "little pond" while another scientist, J.B.S. Haldane, "envisaged the Earth's entire ocean as the setting" (Davies, 1999). Inherent in both theories is a biological prerequisite for water and sunlight as an energy source. Yet even the best equipped bacteria would not have survived the scorching temperatures and massive tsunamis resulting from meteorites that bombarded the Earth's surface 3.8 billion years ago (Davies, 1999).

In 1977 scientists discovered underwater geysers that released mineral-rich water from deep cracks in the ocean floor. These "hydrothermal vents" harbored a variety of life forms, from tubeworms to blind shrimp, which depended on bacteria for food (Gowell, 1998). The ability of these bacteria to use the sulfide in hot water to make their own food demonstrated that hydrothermal vents could sustain dynamic ecosystems entirely independent of sunlight. At a time when the surface of the Earth was experiencing a barrage of meteorite impacts and ultraviolet radiation, hydrothermal vents would have provided a sheltered haven for the first life on Earth (Davies, 1999).

Astrobiologists continue to explore life in extreme environments to provide clues as to how life began on Earth and whether life exists elsewhere in the universe. Lake Vostok, the largest of Antarctica's subterranean lakes, is thought to harbor viable bacteria. The technology scientists develop for future exploration of Lake Vostok may provide applications to the search for life on Europa. If Europa proves to be as volcanically active as other Jovian moons, beneath its icy surface may be an ocean of water warmed by hydrothermal vents (Davies, 1999). These findings in astrobiology research prompt us to wonder how life began on our planet, and whether life is beginning on Europa as it did on Earth 3.8 billion years ago. The proposed curriculum instills within students similar questions, as they wonder about the origin of life on Earth and the prospect of finding life elsewhere in the universe.

Relevance to the Use of Computer Technology in Teaching Science

The dearth of quantitative research on computer technology and learning, and the conflicting nature of these studies demonstrate an inherent need for assessing the effects of computer technology on learning. Based on these previous studies a more indepth study will be conducted on the effectiveness of computers on learning in the elementary science lab. The aforementioned educational movement towards standards-based reform in the 1990's brought about a heightened awareness of the critical role of computer technology in the learning process. Both sets of standards (AAAS and DCPS) emphasize the importance of computers to learning science at the elementary grade level. The AAAS Benchmarks assert that "students should all become comfortable using computers to manipulate information" (AAAS, 1993, 200). "By the end of fifth grade, students should know that computers can be programmed to store, retrieve, and perform operations [such as] ...word processing, diagram drawing, and the modeling of complex events" (AAAS, 1993, 202). The DCPS Science Standards enumerate a more specific set of expectations for computer use. Grade 4 students should use "word processors and internet for reports," graphing programs to analyze data, and "web pages to collect data on related concepts" (DCPS, 2000). The proposed curriculum implements a variety of computer programs for use in word processing, graphing, drawing, and research. The intended classroom purposes and goals of the different computer programs, along with a list of frequently used web sites, are provided in Table 2. A discussion of the actual activities and specific uses of computers in the proposed curriculum can be found in the Methodology section.

Table 2. Computer programs used by the test group with intended uses and products.

Computer Program	**Classroom Uses**	**Products**
Microsoft Word	Data entry	daily lab sheets
Microsoft Excel	Graphs, Charts	pie charts, bar graphs
Broderbund Kid Pix	Drawing	water cycle diagrams, drawings colonies
Internet Explorer Web Sites:		
• http://ga.water.usgs.gov/edu/ • http://news.bbc.co.uk/hi/english/sci/tech/default.stm	Web Activity Research	Water science survey BBC News search
• http://commtechlab.msu.edu/sites/dlc-me/ • http://www.bact.wisc.edu/bact303/b1	Web Activity Research	Microbe zoo web quest Yellowstone web quest
• http://www.gould.edu.au/foodwebs/kids_web.htm • http://www.amnh.org/nationalcenter/expeditions/blacksmokers/black_smokers.html	Web Activity Research	Food web activity Ppt. presentations
• http://www.discovery.com/stories/science/seavents/creatures.html	Research	Ppt. presentations
Microsoft Powerpoint	Presentations	hydrothermal vent presentations

CHAPTER 3

ASSESSMENT OF THE EFFECTIVENESS OF COMPUTER TECHNOLOGY ON LEARNING ASTROBIOLOGY CONCEPTS

Methodology

Overview

The astrobiology curriculum was administered to three classes of Grade 4 students (n=49) at an independent N-6 day school in Washington, D.C. The mean age of all students was 9.6 years. Every class attended science three times a week as a specialist subject, and experienced the three units of the curriculum in the same order. For each unit, two classes featured computer use while the remaining class served as the control group (no computer access). By the end of the curriculum, each class experienced computers twice and served as the control group once (Table 3). Students in both groups chose partners at the beginning of each unit of the curriculum. Nine internet-accessible PCs, adjacent to the lecture and activity space, enabled test group students to work in pairs. Students in the test group completed computer-based activities for every science class, and spent at least 50% of their class time using computers for each unit (Tables 4, 5, and 6). All students experienced the same curricular material, regardless of their grouping. For example, one computer-based activity challenged test group students to use the Microbe Zoo web site to match a given bacterium with its correct description (Appendix 4). Control group students used print-outs of the web site to complete the

Table 3. The division of three Grade 4 classes into test and control groups.

Curriculum Unit	Test Group	Control group	Sample Size test / control
Water	4B & 4C	4A	n=31 / n=18
Microscopic Life	4A & 4C	4B	n=32 / n=17
Hydrothermal Vents	4A & 4B	4C	n=35 / n=14

Table 4.Time spent on computers by the test group during the Water unit.

Day	Topic	Activity Description	Computer Use (in minutes)
Day 1	Water Pretest**	• water pretest • yeast demonstration	N/A
Day 2	Water Introduction	• USGS water science survey • **USGS web site*** • discussion	35
Day 3	Fruit Dehydration	• begin fruit dehydration • **Microsoft word lab sheets*** • prepare potato osmosis cups	15
Day 4	Fruit Dehydration (continued)	• record weights and graph • **Microsoft Excel pie charts*** • Discussion	30
Day 5	Osmosis	• measure and compare diameters • draw osmosis diagrams • **Microsoft word lab sheets***	20
Day 6	Water Cycle	• water cycle game • **EPA web site***	15
Day 7	Water Cycle (continued)	• water cycle demonstration • draw the water cycle • **Kid Pix Studio***	35
Day 8	Solubility	• solubility lab • **EEK water science web site***	10
Day 9	Water Filtration	• design a water filter • diagram the materials used • **Kid Pix drawing program***	25
Day 10	Water Review	• student reference books on water • **BBC News article search on the web*** • **explore links to various web sites ***	30
Day 11	Water Posttest**	• water posttest • student reflections	N/A
		Total computer time	215
		Total class time @ 45 min/day	405
		% of class time spent on computers	53%

* technology-based activities experienced only by the test group.

** not included in total class time.

Table 5.Time spent on computers by the test group during the Microscopic Life unit.

Day	Topic	Activity Description	Computer Use (in minutes)
Day 1	Microbe Pretest**	- microbe pretest	N/A
Day 2	Microbial Cities	- make *Winogradsky Columns* from mud, egg yolks, and sand to culture sulfur bacteria.	0
Day 3	Identifying Protozoa	- use light microscopes to observe protists - choose a protist to draw - **Kid Pix drawing program***	15
Day 4	Culturing Bacteria	- prepare nutrient agar plates to test for colony growth - introductory discussion on bacteria - **Sam sleuth microbe web site***	20
Day 5	Culturing Bacteria (continued)	- observe growth of bacteria on plates - count and draw colonies of bacteria - **Kid Pix drawing program***	35
Day 6	Microbe Zoo	- bacteria scavenger hunt - uses and roles of bacteria in daily life - **Microbe Zoo web quest***	40
Day 7	Life at Extremes	- microbes in extreme environments - **Yellowstone Hot Springs web quest***	35
Day 8	Creation Myths	- analyze creation myths of differ cultures - discuss a scientist's view of creation - **creation myth web quest***	30
Day 9	Origin of Life & Evolution	- discussion of the history of Earth - drawing the geological time scale - **geological time web site***	25
Day 10	Life Beyond Earth?	- discussion with visuals - Video: "Life Beyond Earth" - **Powerpoint presentation on space***	20
Day 11	Microbe Posttest**	- microbe posttest - student reflections	N/A
		Total computer time	220
		Total class time @ 45 min/day	405
		% of class time spent on computers	54%

* technology-based activities experienced only by the test group.

** not included in total class time.

Table 6.Time spent on computers by the test group during the Hydrothermal Vents unit.

Day	Topic	Activity Description	Computer Use (in minutes)
Day 1	Hydrothermal Vent Pretest**	• vent pretest • introduction to hydrothermal vents	N/A
Day 2	Ocean Floor Mapping	• use depth soundings to map ocean floors • graph the 3-D features • **Microsoft Excel***	20
Day 3	Making Hydrothermal Vents	• conduct research on black smokers • make deep sea vents from colored water • **AMNH black smokers web site***	20
Day 4	Food Webs	• Food web activity • Draw a food web powered by sunlight • **Food Web internet activity*** • **Kid Pix drawing program***	25
Day 5	Making Tubeworms	• construct models of tubeworms • **NOVA web site***	25
Days 6	Hydrothermal Vent Life	• discuss life of deep sea vents with visuals • **powerpoint presentation on vent life*** • assign hydrothermal vent project	20
Days 7-8	Hydrothermal Vent Project	• Conduct research on vent life for project • Create a class mural of vent life (control group only) • **Use powerpoint to create a presentation on hydrothermal vents***	90
Day 9	Life Beyond Earth?	• Design a space vessel & deep sea probe to search for life on Europa • **Kid Pix drawing program***	35
Day 10	Hydrothermal Vent Posttest**	• vent posttest • student reflections	N/A
		Total computer time	235
		Total class time @ 45 min/day	360
		% of class time spent on computers	65%

* technology-based activities experienced only by the test group.

** not included in total class time.

same lab sheet. The proportion of time test group students spent on computers, and the curricular differences experienced by test and control group students for each unit are provided in Tables 4, 5, and 6.

Assessment Tools

Table 7 lists the assessment tools used to determine the extent to which technology impacted student learning and provides details concerning their administration and analysis. At the beginning of the curriculum, each student completed a computer survey (Appendix 5) that was modeled after Tobin (1999). The familiarity and extent of computer use among students was surveyed before and after the study using this assessment tool. The degree to which students understood the curricular content was assessed before and after each unit using a battery of pre- and posttests. The tests incorporate a wide variety of testing formats (multiple choice, short answer, drawing, and essay) to accommodate multiple learning styles. In addition to revisiting the material covered on the pretest, the posttest included some additional high-order thought questions. An example of a pretest and posttest administered during the curriculum is provided in the appendix (Appendices 6 and 7). The scores of the pretests were used to assess student understanding of the material that was to be covered in the upcoming unit and the extent to which the control group and test group represented two pools of equally knowledgeable science students. The posttest scores were then used to evaluate the impact of computers on the comprehension of concepts. A student reflections survey accompanied every posttest to gauge student impressions and reactions towards the different methods of instruction (Appendix 8).

Table 7. The assessment tools used, the purpose of each tool, the time administered, and the statistical tests used to interpret the results.

Purpose	Assessment Method	Time Table	# of Times	Statistical Test
How did classroom computer use affect student opinions about technology, and the amount of time spent on computers?	**Computer Survey*** (written)	Before and after entire curriculum	2X	x^2 and descriptive
How did each class initially compare in student academic ability in the sciences?	**Pretest** (written)	Before each unit	3X	t-test
What impact did computer technology have on conceptual understanding?	**Posttest** (written)	After each unit	3X	t-test
How did students compare in their creativity, scientific thinking, and enthusiasm for the subject material?	**Take-home project** (written)	Part of each unit	3X	t-test
How did students compare in their ability to identify themes, and verbally express curricular concepts?	**Individual responses** (audiotape)	After the entire curriculum	1X	x^2
How did students react to the different methods of instruction? Overall, what impressions did students have regarding technology in the science curriculum?	**Student reflections*** (written)	After each unit	3X	descriptive

*modeled after Tobin (1999)

The researcher graded all assessments in an objective manner. Students were assigned a number at the beginning of the curriculum that would be written in lieu of their name on every assessment to maintain anonymity among test and control groups. Rubrics were developed to assess the level of student creativity, scientific thinking, and effort for each of the three take-home projects. Appendices 7 and 8 provide an example of a take-home project (assigned during the microscopic life unit) and the rubric used. The questions included in the audiotape assessment and the rubric used to evaluate student responses to this assessment are also provided in the appendix (appendix 9). One purpose of the audiotape responses was to expand the medium through which students are assessed for curricular knowledge since some students may be better equipped to verbally express curricular concepts than to express their ideas in written formats such as tests and projects (Hopkins. 1993).

Results

The initial computer use survey revealed that most students had used computers for at least four years (80%. n=49): mean=4.3 years. All students had access to a computer at home (100%. n=49) and most (96%. n=49) had Internet access. Most students (82%) spent some time on computers at least 3 days per week (outside of school) (mean=4.0 days. range=0-6). Computers were typically used for more than one activity with the internet being most common (41%), followed by word processing (29%), games (25%), research (23%), and email (23%). With the exception of Microsoft Word (6%), a significant proportion of students responded that they did not feel comfortable using the programs mentioned on the computer survey before the curriculum (Excel=71%, Powerpoint=49%, Kid Pix=45%). Most students felt that computers were fun and helpful (94% and 71% respectively, n=49). Fewer than 8% chose the words "intimidating" or "difficult" to describe computers; none felt they were boring. In general, students were already quite familiar with computers prior to exposure to the computer-based curriculum.

Pretest scores did not significantly differ between test and control groups for any individual unit (water: t=1.0, p=0.31; microscopic life: t=0.75, p=0.45; hydrothermal vents: t=0.045, p=0.96) nor for all units combined (t=0.046, p=0.86). Thus, test and control group students appear to have had comparable levels of curricular knowledge prior to each unit (Figure 1). Posttest scores were significantly greater than pretest scores for control and test groups for all units (t=17.4, p=0), thereby attesting to the success to which students at the Grade 4 level understood the concepts presented in the Astrobiology curriculum. There was no significant difference in posttest scores for students in the test group versus those in the control group for any unit (t=0.99, p=0.33; t=0.75, p=0.46; t=0.59, p=0.56) nor for all units combined (t=0.54, p=0.59) (Figure 2).

Take-home project scores did not significantly differ between test and control groups for the first two units (t=0.21, p=0.84; t=1.2, p=0.24). However, test group students scored significantly higher than the control group for the hydrothermal vent project (t=2.7, p=0.01), and when scores from all units were analyzed together (t=2.2, p=0.028) (Figure 3).

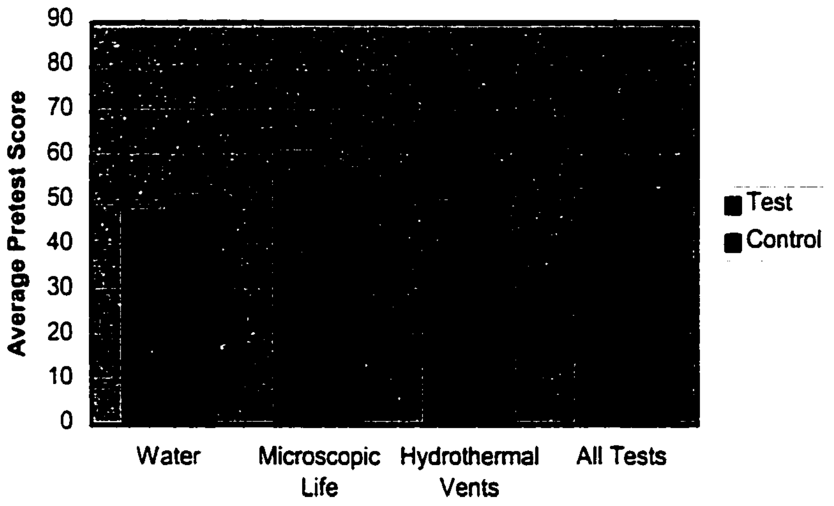

Figure 1. The mean pretest scores for the test and control groups. There was no significant difference for any unit. Sample sizes for the test group from left to right are: n=31, 32, 35, 98; and for the control group: n=18, 17, 14, 49.

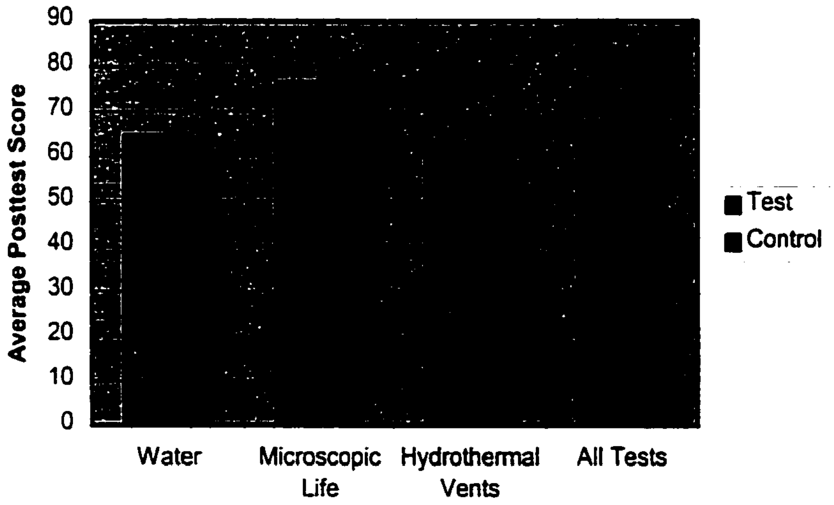

Figure 2. The mean posttest scores for the test and control groups. There was no significant difference in posttest scores between test and control groups for any unit. (see Figure 1 for sample size information).

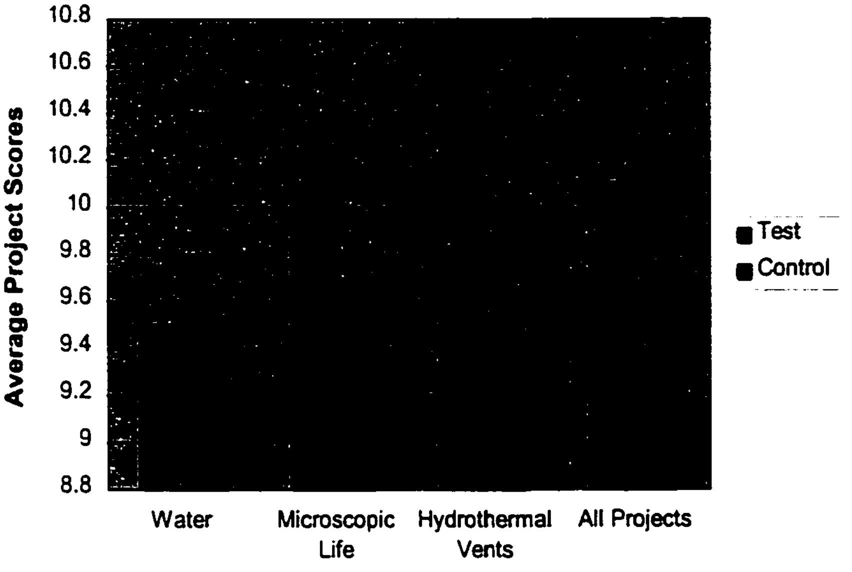

Figure 3. The average take-home project scores for the test and control groups. Scores significantly differed between test and control groups for the hydrothermal vents unit only and when scores for all projects were combined.

For the audiotape assessment, control group students scored significantly higher than the test group for the water unit only ($x^2_3=8.3$, $p<0.05$). There was no significant difference for the remaining two units ($x^2_3=5.2$, $p=0.28$; $x^2_3=6.4$, $p=0.10$), nor for all units combined ($x^2_3=5.2$, $p=0.28$).

Student reflections for all three units revealed that most students felt that computers were helpful in learning science (Figure 4), even though posttest analyses showed no indication of increased learning in response to computer use (Figure 2). In response to *why* they felt computers were helpful, students cited the following reasons: ability to research and gather information (31%); easy access to the internet and helpful websites (29%); ability to learn at a faster pace (18%); and improved understanding of subject matter (11%). Certain activities tended to be more popular among test group students (as shown by the positive percentages), suggesting that the use of computers provided a more positive learning experience for these activities (Table 8). The negative percentages indicate activities in which computers may have provided less favorable learning experiences for a particular activity.

The computer surveys administered before and after the entire curriculum (n=49) were analyzed to gauge changes in student opinion and feelings towards computers. Answers for question six revealed that the number of students who felt comfortable using the four computer programs (Word, Excel, Powerpoint, and Kid Pix) did not significantly differ after experiencing the computer-based curriculum ($x^2_3=0.735$, $p=0.85$). Question eight from the computer survey asked students to choose the method that helped them to

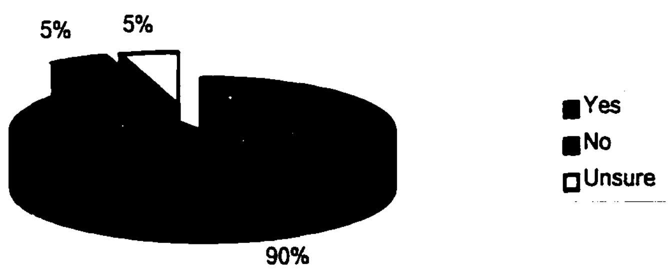

Figure 4. Are Computers Helpful in Learning Science?
Responses of all test group students combined (n=98) for the student reflection assessments.

Table 8: Students were asked to provide their favorite activity when completing the student reflection assessments after each of the three units. Shown below were the students' favorite activities, a description of how each activity differed between the two groups, and the difference in the percentage of students from the test group versus those in the control group that chose the activity as their favorite. Only those activities that showed a significant difference between test and control group students are included in the table. The sign of the percentages (+ and -) suggest the degree to which computers were perceived to be more (+) or less (-) favorable by test group students.

Favorite Activity	Activity Descriptions		% of Students (test – control group)
	Control group	Test group	
Water Filtration	filter designs drawn on pen and paper	filter designs drawn on Kid Pix	-21%
Water Cycle	water cycle diagrams drawn on paper	water cycle diagrams drawn on Kid Pix	+16%
Culturing Bacteria	colony distributions drawn on paper	colony distributions drawn on Kid Pix	-37%
Creation Myths	website printouts are provided as a source of information to answer question.	different websites are provided to search for information on the internet	+7%
Depth Soundings	ocean floor depths are graphed on paper	3-D bar graphs are drawn on Excel	+7%
Life Beyond Earth	website printouts used for research to prepare students for vents take-home project	different websites are provided to search for information on the internet	+18%
Black Smokers	website printouts are provided as a source of information to answer questions	different websites are provided to search for information on the internet	+9%

learn science the best (computers, teacher, books, homework, science, or activities). Similarly, although there was a slight increase in the number of students who felt computers best helped them to learn science (when compared to teacher, books, homework, science, and activities) after the curriculum (question #8), there was no significant difference in student responses before and after the curriculum when all six choices were analyzed together (x^2_3=5.65, p=0.15). Thus, there was no significant difference in the number of students who felt computers were more helpful than the five other methods of instruction after exposure to the computer-based curriculum.

Discussion

In this day and age, when computer usage is increasingly advocated in elementary and secondary school classrooms (Pugalee and Robinson, 1998) (Becker and Ravitz, 1999) (Archer, 1998), it is important to understand how computer technology may best facilitate learning. However, to date, few studies have quantitatively assessed the usefulness of computer-based instruction. For this study, I assessed students' academic progress quantitatively using both oral and written assessments based on a new Astrobiology curriculum. Results indicated no significant increase in student understanding in response to exposure to computer-based activities. Students in the test groups (computer use) failed to score higher than the control groups (no computer use) on the posttests (t=0.54, p=0.59) (Figure 2) and audiotape responses (x^2=5.2, p=0.28). This is in contrast to the limited data available from previous studies. Results from two large-scale studies suggest that computer use positively impacts student academic achievement in non-science areas (Wenglinsky, 1998) (Sivin-Kachala and Bialo, 2000). The third study, which focused specifically on science content, also indicated that computer use enhanced learning (Gardner, *et al.* 1992).

The failure to detect an academic improvement with computer-assisted learning suggests a number of possible explanations: 1) The improvement was present but not detected, 2) The academic improvement was masked by the inhibitory effects of computer use on learning, or 3) Computers had no significant impact on the learning process.

Limitations in the assessment tools support the argument that the academic benefits of computers were present but not detected. The types of questions asked on the posttest and audiotape assessments made little distinction between the knowledge students could gain from computers or from computer printouts. For example, questions 2-7 on the hydrothermal vents posttest (Appendix 7, page 53) referred to specific information on food chains to which students in both groups had access. Likewise, the content emphasized on the posttests may not have been reflective of the extraordinary wealth of information found on the Internet. During the web quests, test group students were able to explore links to a variety of sites, whereas control group students were limited to printouts of specific websites. With the exception of a few open-ended questions that gave students the opportunity to provide knowledge beyond the scope of the curriculum (Appendix 7, page 53, question 8), the posttests primarily focused on information that was accessible to both groups. Therefore, it appears that limitations in the assessment tools may have hindered our ability to detect a difference in academic achievement between the test and control groups.

On the other hand, several lines of reasoning refute the argument that the academic benefits were not detected. The importance of matching instructional style to assessment (Dunn, 1995) (Hein and Price, 1994) (Cornett, 1983) is critical if improvements in student achievement are to be detected. The assessments administered throughout the study were reflective of the researcher's instructional style and presentation of curricular material. For example, the audiotape assessments gave students the opportunity to verbally express broad curricular concepts, a skill developed from frequently asking students questions during class discussions. Additionally, the assessments were designed to ensure student knowledge was assessed adequately and fairly. The posttests consisted of several higher-order thought questions that were challenging enough so that differences in academic achievement could be clearly detected. Other assessments incorporated a wide variety of formats to accommodate diverse learning styles, since research shows that learning is enhanced when curricular material is taught in a manner that engages each student's perceptual preference (Dunn, *et al.* 1989) (Dunn, 1990) (Hein, 2000).

Likewise, adequate controls were used to minimize background noise so that differences in academic achievement in response to computer use could be detected. In contrast to other science teaching studies described in the literature (e.g., Mistler-Jackson and Songer, 2000) (Tobin, 1999), robust control groups were employed throughout my study to ensure that differences in curricular experiences were limited to computer usage. The daily routines and curricular material for each unit were consistent between the two groups, irrespective of the presence or absence of computers (Tables 4, 5, and 6). Since the students were acclimated to a cooperative learning environment and working in pairings of their choice for over a year, I felt that assigned pairings would introduce additional variables to the study (i.e. gender bias, comfort level) (Dunn, 1991). Thus, students in both groups were provided the opportunity to choose partners at the beginning of each unit of the curriculum.

A second explanation for the written and oral assessment data suggests that inhibitory influences of technology might have masked the positive impact of computer use on learning. If students were unfamiliar with computers, it is possible that the learning curve associated with the computer-based curriculum would be great enough to diminish any academic improvements associated with computer use. Although every student (100%) had access to computer at home, there was variability in the number of students who felt comfortable using specific computer programs. A significant proportion of students did not feel comfortable using many of the programs mentioned on the computer survey before the curriculum (Excel=71%, Powerpoint=49%, Kid Pix=45%), in contrast to Word (6%). Although there was a slight increase in the number of students who felt comfortable using the four computer programs after the computer-based curriculum, the difference was not significant ($x^2_3=0.735$, $p=0.85$). Even so, student unfamiliarity with computers is unlikely to have been an inhibitory factor on academic achievement. Most students (80%) had used computers for at least four years, and 82% of students spent some time on computers at least three days per week outside of school. In addition, every student had attended computer class twice a week since kindergarten.

The varying degree to which different computer applications were helpful may account for the inhibitory effect of computers on learning. Computer exercises primarily focused on drawing or entering data were generally regarded by students to be less popular and less useful for learning. For example, activities involving the use of Kid Pix evoked far fewer test group students from choosing these activities as their favorites, as indicated by the negative percentages in Table 8 (water filtration: -21%, culturing bacteria: -37%). Drawing water filter designs on Kid Pix was far more time consuming than the control group alternative, recording this information on paper. As a result, most students in the test group were only able to complete and test one filter design, while many control group students completed over three designs. Likewise, the culturing bacteria activity evoked a negative response from the test group (-37%) because students found the process of drawing colonies on Kid Pix to be tedious and time consuming. On the other hand, computer-based activities structured around content were much more successful. These content-rich activities not only engaged student interest, but also developed critical thinking skills. For example, the Internet web quests (Life Beyond Earth: +18%, Black Smokers: +9%, Creation Myths: +7%) challenged students to selectively search the Web for required information, a process that engaged students to think critically. The success of these computer-based activities primarily depended upon the application, and was irrespective of the computer program used. When Kid Pix was used to draw and provide descriptions of each part of the water cycle (evaporation, condensation, and precipitation), test group students were more engaged than students in the control group who drew the diagrams on paper (water cycle: +16%).

The range in effectiveness of different computer applications suggest that the failure to detect a difference in conceptual learning between test and control groups may be due to the mitigating effect of inhibitory activities on conceptual learning. The oral and written assessments were not sensitive enough to distinguish between the level of conceptual understanding students achieved from content-rich activities (i.e. water cycle) compared to other less effective computer applications (i.e. culturing bacteria). Results from the take-home projects, on the other hand, provided the opportunity to assess the impact of specific computer exercises on learning. Test group students scored significantly higher on the hydrothermal vents project ($t=2.7$, $p=0.01$) (Figure 3), a result that may be attributed to the increased use of computers in preparation for this project. For the hydrothermal vents project, test group students conducted Internet research for an entire class period in preparation for their take-home project. In contrast, control group students referred to printouts of the same websites. Computers were not used in preparation for the water or microscopic life projects. Thus, it appears that Internet research invoked test group students to produce higher quality work for the hydrothermal vents project. For the microscopic life project, websites were handed out as an optional resource for students in both groups. Although insignificant ($t=1.2$, $p=0.24$) (Figure 3), the higher scores of the test group for the microscopic life project may also support a positive effect of computer use.

Inadequate computer time and resources may have diminished the potential benefits of computers to learning. Overall, the computer-based activities administered to the test group were far more time consuming than the control group alternatives. Test group students required more time to grapple with such issues as memory (computer speed), formatting (entering text), saving documents, and the proximity of computers to the lab tables for data entry. In addition, the student to computer ratio for this study (2:1) did not provide students the choice to work alone. Studies have shown that cooperative learning is not effective for every child and some students display a perceptual preference to work alone (Hein, 2000) (Dunn, 1991). Thus, the limited number of computers and inadequate computer time may have negatively influenced the learning process.

A third explanation for the statistical results suggests that computers made no difference in the learning process. The limited data available from previous studies offer little convincing evidence to substantiate or refute this claim. Results from Tobin (1999) found no significant difference in conceptual learning between seventh grade science students exposed to computers versus those exposed to hands-on activities alone. However, curricular inconsistencies in the daily routines of the two groups introduced additional variables to the study. On the other hand, Mistler-Jackson and Songer (2000) claimed that the use of computers to teach middle school students resulted in significant improvements in science inquiry. Yet the absence of control groups (group without computer exposure) prevented the proper assessment of computers on learning.

Although the statistical results from this study do not demonstrate increased learning in response to computer usage, results from the student reflections suggest that computers did facilitate learning. For example, in response to the question of whether they felt computers were helpful with learning science, 90% of students answered yes, particularly when doing research (31%), visiting websites (29%), and for rapid learning

(18%). These findings were consistent with the favorite activities students provided on the student reflections. Activities involving the use of the internet for research appeared three times in Table 8 as a positive percentage (creation myths: +7%, life beyond earth: +18%, black smokers: +9%), indicating that test group students perceived this use of the computers to be particularly useful in learning science. Similarly, many studies have found the use of the Internet for research to be a powerful computer application for learning science (Songer, 1998) (Pugalee and Robinson, 1998) (Becker and Ravitz, 1999) (Santos and Oliveira, 1999).

The inherent connection between constructivist philosophy and the use of computers in the classroom (Becker and Ravitz, 1999) (Perry, 2000) also refute the claim that computers had no impact on learning. Studies have shown that computer technology immerses students in rich environments of information and experience, thereby enabling constructivist goals to be accomplished (Archer, 1998) (Cobb, 1999) (Songer, 1998). When focused on content, the raw material of constructivism, computer exercises may facilitate this approach towards learning. For example, content-rich applications of Kid Pix gave students the opportunity to demonstrate their knowledge of each step of the water cycle or the characteristics of food chains. The use of the Internet for research (i.e. powerpoint presentations, take-home projects) and for authentic learning activities (i.e. Internet web quests) has also been shown to facilitate knowledge construction (Becker and Ravitz, 1999) (Pugalee and Robinson, 1998) (Hargis, 2001).

Finally, the argument that computers had no impact on learning overlooks the skills students may acquire from exposure to a wide variety of computer applications

(Cardelle-Elawar and Wetzel, 1995) (Wenglinsky, 1998) (Santos and Oliveira, 1999) (Songer, 1998), many of which cannot be detected using traditional testing methods. For example, the use of computers to create slide shows on hydrothermal vents developed within students a variety of skills (sequencing, applying concepts, identifying themes, information discretion) that would not effect academic achievement the same way that knowledge is traditionally tested. The skills acquired from computer use empower students to express their ideas more effectively, thereby leading them to take greater pride in their work (Tobin, 1999) (Mistler-Jackson and Songer, 2000) (Perry, 2000). The use of Powerpoint, coupled with the colorful pictures students downloaded from the Internet, facilitated their ability to produce high quality presentations that would be difficult to achieve on paper. Likewise, the food chain and water cycle activities enabled test group students to create diagrams using Kid Pix that were visibly more professional and aesthetically pleasing than the diagrams control group students drew by hand.

The previous discussion supports the hypothesis that computers had a positive impact on learning. Both the 1) inability to detect a response, and the 2) inhibitory effects of computer use on learning best explain why an academic improvement was not seen in response to computer usage. Limitations in the posttest and audiotape assessments may have overlooked important skills and tangential knowledge acquired from computer use. Time constraints and the limited number of computers may also account for the failure to detect a positive response to computer use. Inhibitory computer exercises may have masked the academic benefits of content-rich computer applications that more successfully achieved a constructivist approach towards learning. Yet despite the competing inhibitory influences of computers, test group students were on par with the control group for every assessment, and developed valuable skills in the process.

The curriculum developed to assess the effects of computer use was based upon the science of Astrobiology. The current research objectives of the NASA Astrobiology program were the fundamental source of inspiration for building this curriculum: 1) To discover the process by which life begins and evolves; 2) To search for the existence of life elsewhere in the universe; 3) To plan for the future of life on Earth and beyond (NASA, 2001). Three themes were derived from NASA's objectives (water, microscopic life, and hydrothermal vents) to serve as a conceptual framework. Relevant hands-on activities were created and ordered to establish a rational progression of concepts within each theme. The constructivist approach of the curricular framework enabled students to develop a deeper understanding of broad curricular themes. For example, an understanding of the basic concepts of water enabled students to grasp the significance of microscopic life and hydrothermal vents to the search for life beyond Earth. The success to which students at the Grade 4 level understood the concepts presented in the Astrobiology curriculum was evident in the heightened level of achievement students attained after taking each posttest. Students in both groups scored significantly higher on the posttests than on the pretests for all units ($t=17.4$, $p=0$). The significance of this result becomes more apparent when considering the fact that the posttests were far more challenging than the pretests.

The primary focus of the curriculum was to instill within students an awareness and an appreciation of current Astrobiological research. Educators lacking a sufficiently strong science background may find the process of creating science curricula related to current research to be difficult and time consuming. As an alternative, many existing science curricula built upon a wide variety of scientific disciplines may be used in the classroom (TERC, 2001) (One Sky Many Voices, 2001) (SETI, 2001) (MBL, 2001). "Astrobiology in Your Classroom" is one example of a K-12 science curricula based upon current Astrobiological research (TERC, 2001). Individual educators have been equally successful at creating science curricula connected to current research for the elementary and secondary grades (Adams, 2000) (Lester, 2000) (Viotti, 2001) (Klug, 2001). For example, "The Sun in Time" curriculum was designed to enhance awareness of current findings in Archaeoastronomy (solar science) for students in Grades 5-8 (Adams, 2000). The existence of science curricula such as these demonstrates that educators and scientists have been successful at using current research to teach students science concepts.

The quantitative results presented in this study illustrate the complex nature of computer use on learning. Several studies on learning in non-science areas found positive correlations between computer use and conceptual learning. The use of computer technology for reading and language arts in the elementary grades has been demonstrated to provide a learning advantage in vocabulary, reading comprehension, and spelling (Schultz, 1995) (Stone, 1996) (Stine, 1993) (Scrase, 1998) (Hollen, 1987). Likewise, elementary students exposed to technology-enhanced mathematics curricula demonstrated a conceptual understanding superior to those students receiving traditional instruction (Elliott and Hall, 1997) (Butzin, 2001) (Underwood, *et al.* 1996) (Stone, 1996)

(Fletcher, *et al.* 1990). Though there are likely to be comparable academic benefits for teaching science, more quantitative research must be conducted to gain a better understanding of how computer technology may best facilitate learning in this academic discipline. In particular, future studies should be conducted on larger sample sizes and over long periods of time to more effectively assess the academic impact of computer technology on learning. Future research must continue to develop or assess already existing computer applications that better connect learning to content, thereby maximizing the usefulness of computers to conceptual learning.

John Dewey, one of the most influential educators of the twentieth century, firmly advocated a socially relevant and child-centered approach towards learning. The role of the teacher as facilitator was critical in providing engaging learning experiences through which students could acquire knowledge (Dewey, 1998). The innovation of computers half a century later would radically alter this relationship between teacher and student. This study illustrates the complexity of the use of computers for teaching. To be effective, computer use in the classroom should focus on content in such a way that students are actively engaged in the learning process. Classroom computer use will rarely serve as a substitute for teacher-student interaction (Archer, 1998) (Healy, 2000), since the teacher's role as facilitator is critical in clearly outlining the goals and expectations of every computer-based activity. On the other hand, computers do provide a powerful alternative to books in fulfilling the need for social relevance, particularly with the wealth of current information the Internet provides for research (Pugalee and Robinson, 1998) (Songer, 1998). This study suggests that the potential of computers to serve as powerful learning tools primarily depends upon their use in the classroom. If computer technology is to become an integral component to education, research must continue to assess the most effective applications for learning.

APPENDICES

Appendix 1. A curriculum overview of the water unit.

I. WATER **Why is water essential to life?**

TOPIC	ACTIVITY	QUESTIONS	CONCEPTS	PROCESS SKILLS
Importance To Life	Yeast	How do we define life? What does life need to grow and reproduce?	All living things eat, breath, grow & reproduce. Life needs water & energy.	Making observations Generalizing concepts
	Water Trivia	How much water does it take to grow a hamburger?	The importance of water in our everyday lives.	Making predictions Generalizing concepts
	Fruit Dehydration	How does the weight of an apple change before & after dehydration?	All life contains water and thus needs water to survive	Making predictions Deductive reasoning Graphing
	Potato Osmosis	Why do potato slices shrink when placed in saltwater?	Water transport in cells.	Making observations Problem solving
Properties	Water Cycle Game	Where on our planet does water tend to evaporate and condense?	Water cycle: evaporation, condensation, precipitation	Making observations Making inferences Sequencing
	Solubility Lab	Which dissolves more substances, water or vegetable oil? Why is this important to life?	Water is the universal solvent.	Making observations Generalizing concepts
Distribution	Water Filtration	What filter design would best clean dirty river water?	Water filtration and purification is a costly and complex process.	Problem solving Inductive reasoning Making connections

Appendix 2. A curriculum overview of the microscopic life unit.

II. MICROSCOPIC LIFE **Where do we find bacteria and why do scientists believe the first life on Earth resembled bacteria?**

TOPIC	ACTIVITY	QUESTIONS	CONCEPTS	PROCESS SKILLS
Visual Perspective	Microscope Intro	A light microscope allows us to see images how many times larger than our eyes?	Light microscopes allow us to see living things that ordinarily are too small to see.	Using scientific tools Following procedures
	Identifying Protozoa	How are protists similar to plants and animals?	Many microorganisms can live in just one drop of water.	Using scientific tools Making observations
Bacteria	Culturing Bacteria	What do bacteria need to grow? Which petri dish showed the most colonies?	Even smaller than protozoa are Bacteria; they are ever present.	Following procedures Making observations Making inferences
	Microbe Zoo Activity	How are bacteria useful in our daily lives?	Not all bacteria are harmful; they benefit us in many ways.	Retaining information Identifying themes
Life at Extremes	Yellowstone Web Quest	How do temperature limits of animals & plants differ from protozoa and bacteria?	Simpler organisms are able to adapt to extreme environments.	Observing trends Making inferences Graphing data
	Microbial Cities	What do these bacteria need to grow and where did they originally come from?	Life can thrive without oxygen, CO_2, or light.	Following procedures Making observations Making connections
Origin of Life	Creation Myths	How do different cultures around the world explain the origin of life?	Myths were the best way people could explain scientific truths.	Identifying themes Making connections
	Origin of Life & Evolution	What does geological time tell us about the history of life on Earth?	Bacteria are the best candidates for the first life on Earth.	Posing relevant questions Retaining information
	Life Beyond Earth?	Is there life beyond Earth?	Water is potential indicator of life on other planets and moons.	Applying concepts Generalizing concepts

Appendix 3. A curriculum overview of the hydrothermal vents unit.

III. <u>HYDROTHERMAL VENTS</u> **How do hydrothermal vents support life and why do some believe life on Earth began there?**

TOPIC	ACTIVITY	QUESTIONS	CONCEPTS	PROCESS SKILLS
Ocean Floor Features	Depth Soundings	How did navigators disprove the belief that the ocean floor was flat?	Depth soundings by navigators confirmed that the ocean floor is not flat. The deepest canyons and highest mountains are found at the ocean floor	Measurement skills Graphing Skills Applying concepts
Hydro-thermal Vents	Making Hydrothermal Vents	Why is heated water an essential feature of hydrothermal vents?	Mineral-rich, hot water rising from vents supports a wide variety of life.	Following procedures Making observations Applying concepts
	Food Webs	How are vent food webs unique from those found anywhere else on Earth?	Vent food webs need no sunlight. Bacteria are the main producers.	Sequencing Identifying themes Generalizing concepts
	Powerpoint Slide Show	What types of organisms would I find at a vent and what would they look like?	Hydrothermal vent communities consist of giant clams, mussels, tubeworms, and spider crabs.	Identifying themes Generalizing Concepts
	Making Tubeworms	Given that tubeworms lack a mouth or digestive system, how do they feed?	Residing bacteria feed tubeworms in a symbiotic relationship.	Following procedures Generalizing concepts Sequencing
	Hydrothermal Vent Presentation	What are the basic parts and functions of vent organisms?	Vent organisms tend to be larger, but share many similarities with typical ocean animals.	Making connections Sequencing Generalizing Concepts
Life Beyond Earth	Designing Space Vessels	What features would you include in a space vessel designed to search for life on Europa?	Liquid water and possibly hydrothermal vents may exist beneath Europa's icy surface.	Following procedures Making observations Applying concepts

Appendix 4. An example of a computer-based activity using the Microbe Zoo web site.

MICROBES OF THE MONTH

Directions: Match each bacterium with its correct description on the right.

_____ Symbiont from the deep	a) they thrive in boiling water
_____ Sewage sludge eaters	b) they help control pests but also cause food poisoning
_____ Bacillus infernus	c) these were found in a meteorite from Mars that landed in Antartica
_____ Pyrococcus furiosus	d) they make food for tubeworms at the bottom of the ocean
_____ Agrobacterium	e) they live deep underground below rocks and soil where there is no light or oxygen
_____ Bacillus cereus	f) they help clean up gasoline spills by breaking down toulene.
_____ Martian Bacillus	g) this microbe lives in our large intestine and makes vitamin K to keep us healthy.
_____ Escherichia coli	h) release CO_2 as they break down sewage
_____ Anaerobic toulene degrader	i) this microbe invades living plants and forces them to make "bacteria food."

Appendix 5. A computer survey administered before and after the entire curriculum unit.

COMPUTER SURVEY

Circle an answer from the choices below:

1) Do you have a computer at home?

yes **no**

2) If so, does your computer have access to the internet?

yes **no**

3) How many years have you been using computers?

1 year **2 years** **3 years** **4 years** **5 years or more**

4) Not including computer class, how many days per week do you use computers? (at home, school, or at a friend's house)

never **1** **2** **3** **4** **5** **6 or 7**

5) For what purpose do you use computers most often? (choose up to 3 items)

research **play games** **internet** **graphics**

word processing **email** **play CDs**

6) Which computer programs do you feel most comfortable using? (choose as many as you want)

Excel **Powerpoint** **Word** **Hyperstudio** **Kid Pix** **Inspiration**

7) Which word describes how you feel about computers? (choose 1 or 2 answers)
computers are:

helpful **intimidating** **fun** **boring** **difficult**

8) What do you think helps you learn science the best? (pick 2)

activities **computers** **books** **teacher** **homework**

Appendix 6. An example of a pretest administered to students in the test and control groups.

HYDROTHERMAL VENT PRETEST

_______ 1) If you emptied the water from every ocean on Earth, how would the ocean floor look?

a) flat and smooth
b) rolling hills and valleys
c) tall mountains and deep canyons
d) none of the above

_______ 2) Today, scientists measure how deep the ocean floor is by:

a) dropping a sounding line (rope) with weights attached
b) using sonar, or sound waves
c) using light waves
d) it is not possible to measure the depth of the ocean

_______ 3) The black "smoke" released from deep sea vents at the bottom of the ocean is:

a) the same as smoke from burning wood
b) full of gases that are toxic to life
c) hot water mixed with minerals
d) hot water mixed with mud and sand

_______ 4) The temperature above a deep sea vent is

a) close to the temperature that water freezes (30C)
b) the same temperature that water boils (100C)
c) 3 times higher than the boiling point of water (300C)
d) impossible to measure

_______ 5) What type of life would you expect to find near deep sea vents?

a) only bacteria
b) clams, crabs, and bacteria
c) fish, sharks, and ells
d) no life at all

________ 6) All food webs on Earth

a) begin with an organism that makes their own food
b) are driven by the sun's energy
c) begin with plants
d) all of the above

_______ 7) Most deep sea vents have been found 2 miles below the surface of the ocean. Which of the following would you choose to explore these vents?

a) you could explore these vents in a scuba diving outfit
b) use a submarine - the water pressure would crush a human
c) use a submersible – the water pressure would crush a submarine
d) the water pressure is too high for any human or vessel to visit

________ 8) Which of the living things below can make their own food?

a) only plants
b) only bacteria
c) animals and plants
d) all plants and some bacteria

Appendix 6 (continued)

IN YOUR OPINION:

1) Where do you think life began on Earth 3 billion years ago?
    - Circle one of the four choices below:

Life came to Earth in a meteorite from outer space

Life began at the ocean surface bathed in sunlight

Life began on land

Life began on the ocean floor near deep sea vents

- Why did you choose the answer above?
  Or, explain why you did not choose one of the other answers.

2) Create an ocean food chain using the organisms below:

protists shark algae fish shrimp

3) What type of living thing is found at the bottom of the food chain above?

4) Where does the energy of this food web come from?

5) Now create your own food chain using four or more organisms that live on land:

6) How is your land food chain similar to the ocean food chain?

7) Why are plants called "producers" and animals called "consumers?"

[Hint: Think about what animals and plants do that give them these names]

Appendix 7. An example of a posttest administered to students in the test and control groups.

HYDROTHERMAL VENT POSTTEST

_____ 1) If you emptied the water from every ocean on Earth, how would the ocean floor look?
a) flat and smooth
b) rolling hills and valleys
c) tall mountains and deep canyons
d) none of the above

_______ 2) Today, scientists measure how deep the ocean floor is by:
a) dropping a sounding line (rope) with weights attached
b) using sonar, or sound waves
c) using light waves
d) it is not possible to measure the depth of the ocean

_______ 3) The black "smoke" released from deep sea vents at the bottom of the ocean is:
a) the same as smoke from burning wood
b) full of gases that are toxic to life
c) hot water mixed with minerals
d) hot water mixed with mud and sand

_______ 4) The temperature above a deep sea vent is
a) close to the temperature that water freezes (30C)
b) the same temperature that water boils (100C)
c) 3 times higher than the boiling point of water (300C)
d) impossible to measure

_______ 5) What type of life would you expect to find near deep sea vents?
a) only bacteria c) fish, sharks, and eels
b) clams, crabs, and bacteria d) no life at all

_______ 6) All food webs on Earth
a) begin with an organism that makes their own food
b) are driven by the sun's energy
c) begin with plants
d) all of the above

_______ 7) Most deep sea vents have been found 2 miles below the surface of the ocean. Which of the following would you choose to explore these vents?
a) you could explore these vents in a scuba diving outfit
b) use a submarine - the water pressure would crush a human
c) use a submersible – the water pressure would crush a submarine
d) the water pressure is too high for any human or vessel to visit

_______ 8) Which of the living things below can make their own food?
a) only plants c) animals and plants
b) only bacteria d) all plants and some bacteria

Appendix 7 (continued)

IN YOUR OPINION:

1) Where do you think life began on Earth 3 billion years ago?
- Circle one of the four choices below:

Life came to Earth in a meteorite from outer space

Life began at the ocean surface bathed in sunlight

Life began on land

Life began on the ocean floor near deep sea vents

Why did you choose the answer above?
Or, explain why you did not choose one of the other answers.

2) Create your own food chain using at least five organisms that live on land:

3) What type of living thing is always found at the bottom of every food chain on land?

4) Where does the energy of this food web come from?

5) Why are plants called "producers" and animals called "consumers?"
[Hint: Think about what animals and plants do that give them these names]

6) Name as many organisms as you can think of that live at hydrothermal vents:

In general, how do the living things you listed above get their food?

7) Describe two things that make life at hydrothermal vents different from life on land:

8) It is the year 2030, and you have been asked to attend a meeting with many famous scientists from across the world. You propose to design a spacecraft to visit Jupiter's moon Europa. Two scientists laugh at your proposal and argue that you would not find life on such an icy and lifeless moon. What would you say to convince the group of scientists that they should send a spacecraft to Europa?

Appendix 8. A survey which accompanied every posttest to gauge student impressions and reactions towards the different methods of instruction.

STUDENT REFLECTIONS...

Describe your favorite activity or day in science during our last unit:

What did you *like* most about the last unit?

Do computers help you with learning science?

- And why do you think so?

What did you *dislike* most about the last unit?

Appendix 9. An example of a take home project assigned during the Microscopic Life unit.

microbe hunter

You are a world famous microbe hunter. You have found microbes at every corner of the earth, from the boiling waters of Yellowstone to the door knobs of St. Patrick's. One day you stumble upon a previously undiscovered species of bacteria. Thank goodness you brought a microscope to observe these fascinating creatures. How would you describe these bacteria?

Be sure to include:

- What name will you give this new type of bacteria?
- Where did you find these bacteria? Describe their environment.
- Where does your bacteria get the energy it needs to survive?
- Is your bacteria able to move? If so, how does it move?
- How often does your bacteria reproduce? (make more copies of itself)

Draw your bacteria on a separate page:

1) What does one bacterium look like under the microscope? Show the color and shape (spiral, round, rod-like).

2) What does a colony of many of these bacteria look like? Draw a round dish with the colonies growing inside (as we did in class).

Be creative and thoughtful. I look forward to seeing the new microbes you have discovered!

PROJECT DUE ON ____________________

Appendix 10. An example of a rubric used to assess take home projects.

MICROBE HUNTER

GRADING SHEET

GUIDELINES **8 7 6 5 4 3 2 1**

Name ____

Environment ____

Habitat description ____

Energy source ____

Movement ____

Reproduction ____

Drawings:

individual ____

colony ____

	Exceeds Expectations	Meets Expectations	Below Expectations	Unsatisfactory
CREATIVITY	4	3	2	1
EFFORT	4	3	2	1
SCIENTIFIC THINKING	4	3	2	1

TOTAL POINTS ____ **NAME** ____________________

Appendix 11.The questions asked to students for the audiotape assessment. Provided beneath each question is the rubric that was used to assess the responses.

AUDIOTAPE QUESTIONS:

#1 Give the two most important reasons why you think water is important to life.

4 = gave 2 important reasons (water cycle, essential to life, indicator of ET life)
3 = gave 1 important reason
2 = superficial response – gave only one reason
1 = unrelated response

#2 Most scientists believe bacteria were the first life on Earth and probably the only living things on Mars and Europa. What is it about bacteria that make scientists believe this?

4 = complete explanation/evidence of reasoning
3 = mentioned at least 2 important factors (fossils, extreme life, evolution)
2 = mentioned 1 important factor
1 = unrelated response

#3) Why are deep sea vents important to our search for life beyond Earth?

3 = relate findings of hydrothermal vents to other planets
2 = demonstrate basic understanding of vents (food chains, bacteria, no sunlight)
1 = superficial/unrelated response

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