Integrating spatial thinking into the curriculum through geographic information systems and the Santa Ana River watershed

Joaquín Javier Baca

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INTEGRATING SPATIAL THINKING INTO THE CURRICULUM THROUGH GEOGRAPHIC INFORMATION SYSTEMS AND THE SANTA ANA RIVER WATERSHED

A Project
Presented to the
Faculty of
California State University,
San Bernardino

In Partial Fulfillment
of the Requirements for the Degree
Master of Arts
in
Education:
Environmental Education

by
Joaquin Javier Baca
June 2007
INTEGRATING SPATIAL THINKING INTO THE CURRICULUM THROUGH GEOGRAPHIC INFORMATION SYSTEMS AND THE SANTA ANA RIVER WATERSHED

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Approved by:

Dr. Darleen Stoner, First Reader

Dr. Gary A. Negin, Second Reader

Lisa M. Pierce, Water Resources Institute, Third Reader
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ABSTRACT

GIS software is utilized to visualize and analyze the dynamic earth and human processes of the Santa Ana Watershed in educational lessons for secondary school students. Topics covered in the activities include math, earth sciences and literature. The activities use the constructivist place-based learning approach to teach environmental knowledge thus helping increase students' spatial thinking. Future impacts of the project include encouraging educators to create similar GIS projects with local watershed data sets. Activity lessons are correlated to the National Science Standards in Secondary Education in areas of Science and Technology and Science in Social and Personal Perspectives.

The maps and activities are presented through ESRI ArcReader© software. The data files were provided by Santa Ana Watershed Project Authority and California State University, San Bernardino, Capital Planning and Design Construction.
ACKNOWLEDGMENTS

I gratefully wish to thank the following people for their generous assistance and contributions to this final work. I especially would like to thank Dr. Stoner and Lisa Pierce for their expertise, guidance and mentorship.

- Darleen K. Stoner, Ph.D. - Department of Environmental Education, CSUSB
- Lisa M. Pierce, M.A. - Water Resources Institute, CSUSB
- Dr. Gary A. Negin, Ph.D. - Department of Language, Literacy and Culture Education, CSUSB
- Dan Filadelphia - Capital Design & Planning Department, CSUSB
- Mark R. Norton, M.P.A., P.E. - Santa Ana Watershed Project Authority
- Peter Vitt - Santa Ana Watershed Project Authority
- Amy M. Gray - U.S. Army Corp of Engineers
- Laura A. Borg - Department of Environmental Education, CSUSB
DEDICATION

Dedicated with love to my wife Yolanda, who supports my "nerd, water and computer stuff."
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CHAPTER ONE

BACKGROUND

With the pervasiveness of technology today, it has become imperative for students to begin utilizing technology as early as possible in their education. With internet sites, such as Google Earth and Mapquest, the use of technology today allows students to visualize and connect in ways unheard of just a decade ago. From laptops and cell phones, to wireless internet and new software, students have become adept at using new tools in everyday life even if they do not realize it. At the same time many educational tools have remained the same. As the joke goes,

Rip Van Winkle awakens in the 21st century after a hundred-year snooze and is, of course, bewildered. Men and women dash about, talking to small metal devices pinned to their ears. Young people sit at home moving miniature athletes around on electronic screens. Airports, hospitals, shopping malls, every place Rip goes just baffles him. But when he finally walks into a schoolroom he knows exactly where he is.

"This is a school, we used to have these back in
1906. Only now the blackboards are green." (Time, 2006, p. 50)

Students today must begin to visualize the world outside of the traditional pedagogical parameters. New technologies will increasingly be an important part of the solution. Geographic Information Systems (GIS) software will be one of the more powerful of the new tools. Although presently not widely used in secondary education, GIS software has been shown to be a beneficial educational tool to analyze and integrate a variety of data (Elder, 2003).

Wittgenstein wrote (1921, p. 3), "What can be said can be said clearly." In order to make this statement true there must be changes made in the way people speak today. It has become apparent that today's society in large part has imposed itself with extremely limited boundaries. In today's societies the world speaks in several "languages"; these languages include cultural, emotional, economic and technological tongues, necessitating a fluency that is not often provided in modern classrooms. GIS, with its emphasis in spatial thinking, is an important new tool in technological tongues.

Spatial thinking can be defined as "skills consisting of declarative and perceptual forms of knowledge and some
cognitive operations that can be used to transform, combine, or otherwise operate on this knowledge (National Research Council, 2006, p. 5). Through spatial thinking, students can visualize relationships of objects within various locations and science disciplines; they can perceive, remember and analyze the dynamic properties of these objects and fully understand the relationships among them.

With the advent of Google Earth, ESRI's ArcExplorer©, Mapquest online maps and their technology, the general public has increasingly become aware of the power of spatial data. In order to expand the use of technology it is required that we increase the integration spatial thinking into future education curriculum. Using GIS software in projects whereby students gather and analyze information about the local community will allow them to incorporate aspects of their home communities, to develop critical thinking and see relevance when finding answers to local environmental issues.

Current educational models focus on an academic specialization approach which has led to students becoming experts in specific areas (Orr, 1994). The result of this approach has been the development of citizens who understand their discipline, but do not understand the
relationships between their areas of study and how these areas interact with other disciplines. David Orr emphasized the need for students to use a multi-disciplinary approach to think across disciplines (1994).

In this master’s project, I have developed exercises for secondary science students using ESRI’s ArcReader© GIS software that can be used as stand alone activities or incorporated into existing science curriculum. The results provide a model that addresses the obstacles in offering interdisciplinary approaches to education.

This project incorporates the following: constructivist theory, which recognizes that students construct new understandings by combining previous understandings with new discoveries (Wellman, 2005); place-based learning, or the process that uses the local environment and community as the context for learning; and environmental education, “which is aimed at producing a citizenry that is knowledgeable concerning the biophysical environment and its associated problems, aware of how to help solve these problems, and motivated to work toward their solution” (Stapp et al., 1969, p. 30).

Through ESRI’S GIS packages, students will be introduced to geographic information systems and spatial
thinking. By utilizing the software ArcGIS® and its related extensions as tools, students will understand the usefulness of technological software when comparing various components of their environment. The activities I provide include exploration of the Upper Santa Ana River Watershed and its related natural and human components. Students should achieve a basic understanding of watershed dynamics and of various educational disciplines and their inherent inter-connectedness. The activities are designed to not only build on previous lessons, but to incorporate aspects of various natural and human science disciplines and how they relate to watershed systems. Lessons include hydrology, biology, endangered species, economics/industries and the role of municipal water agencies.

With the need for up-to-date curriculum, schools often find themselves in a budget crunch. This project is primarily based on low cost educational curriculum available through free downloadable GIS software from ESRI, along with easy to understand instructions and activities. With the introduction of GIS systems into classrooms I hope to inspire educators to expand their GIS curriculum with students by utilizing activities that use local community data acquired by the students.
CHAPTER TWO
REVIEW OF THE LITERATURE

Introduction
Incorporating GIS in today's educational curriculum can be an important tool in expanding current teaching models as well as a significant tool of educational reform. GIS can be effective in promoting critical thinking and spatial awareness. GIS can also function well as an inter-disciplinary approach to education. GIS provides methods with which to explore alternative responses for specific problems and situations (ESRI, 1995). GIS software alone does not contain or present the answer to any posed question; within the software, people establish parameters and ask questions in an attempt to receive their answer. Students must use their critical thinking skills to define what constitutes an answer to their question.

This literature review includes an overview of environmental education and specifically focuses on understanding its value in place-based learning and constructivist learning. The use of GIS software and activities, especially when correlated to National Science Education Standards, can be used to enhance these types of
educational objectives. Selected materials are also presented to provide justification for the infusion of spatial thinking into the curriculum. Findings from research pertaining to GIS in the classroom as well as GIS utilization by government or university agencies are also included.

The goal of this project is not only to provide an effective tool for incorporating GIS into environmental education in the classroom, but also to provide a resource for teaching professionals looking to expand their instruction in spatial thinking. The next three sub-sections review the literature relevant to this goal. First, the education approaches of constructivism and place-based learning are reviewed. Next, recent literature on the definition and importance of spatial thinking in today's world is discussed. Finally, current GIS resources for educators are considered and an exploration of how GIS might be incorporated into the existing curriculum is offered.

Environmental Education

Definition of Environmental Education

"Environmental Education (EE) is aimed at producing a citizenry that is knowledgeable concerning the biophysical
environment and its associated problems, aware of how to help solve these problems, and motivated to work toward their solution" (Stapp et al., 1969, p. 30). Stapp’s definition of EE provides a clear understanding of people as an inseparable part of their environment. It also iterates that an understanding of the natural environment as well as a broad awareness of real world environmental issues must be addressed in order for people to develop an attitude that will motivate themselves to take action in solving environmental issues.

Stapp’s definition of EE was reinforced during the Intergovernmental Conference on Environmental Education in 1977, during which The Tbilisi Declaration (2005) was adopted. This declaration recognized human’s increasing ability to transform their environment and upset the balance of nature. An important set of goals, objectives and principles which closely mirror Stapp’s definition of EE were developed and included in The Tbilisi Declaration.

**Place-Based Learning**

An important aspect of EE involves developing the environmental sensitivity of people. An individual who is environmentally sensitive has a strong sense of attachment to their natural environment and is motivated to protect
The development of environmental sensitivity can be achieved through the use of place-based education.

Place-based education focuses on using the local community and environment as a starting point to teach education concepts. "Emphasizing hands-on, real world learning experiences, this approach to education increases academic achievement" (Sobel, 2004, p. 7). David Sobel stated that place-based education is really "desirable environmental education" (p. 9). Place-based education takes students back to the basics of their local communities, allowing them to connect with the natural and built environments in a more intimate and personal manner. The bonds that form between the students and their place during place-based lessons are vital components of developing environmental sensitivity.

**Constructivist Learning Theory**

When describing the importance of place-based education, Sobel mentioned that "hands-on" approaches often enhance academic achievement (2004, p. 7). The term "hands-on," in the field of education, most often refers to a constructivist learning approach. The constructivist theory of learning encourages individuals to construct new knowledge from a pre-existing framework of knowledge based on their own experiences (Piaget, 1950). Constructivist
teaching theories suggest that teachers should act as facilitators of knowledge, with students taking a more active role in their own learning, rather than teachers simply presenting concise content as in traditional methods (Von Glasersfeld, 1989).

In “Environmental Education as a Model for Constructivist Teaching,” Klein and Merritt (1994) compared the goals of EE with the tenets of constructivism. They suggested that through the utilization of both models of education, students would achieve the ability to investigate, analyze, evaluate, and apply environmental actions. Through the combination of place-based learning and constructivist methods, students would be able to apply their skills to solve real world environmental problems (1994).

**Value of National Education Standards**

The [National Science Education Standards](#) developed by the National Research Council (1996) provide classroom correlations and standards for educators. The standards ensure that students are not only scientifically literate but possess necessary the reasoning and critical thinking skills required for modern society. Incorporating GIS into the existing curriculum, as defined under the framework of
The National Science Education Standards do not provide lesson plans or curricula, but instead lay down a framework for six different aspects of science education: standards for science teaching, standards for professional development for teachers, standards for assessments, standards for science content, standards for science education programs, and standards for science education systems. These standards are designed to ensure the development of scientific literacy in students.

Geographic Information Systems in Education Literature

This portion of the literature review provides summaries of reports pertaining to current research, rationales, and case studies which support the integration and use of GIS software into secondary school curricula. This literature demonstrates the importance of developing spatial awareness in modern classrooms.

A current report by the National Research Council (NRC), Learning to Think Spatially (2006), examined the importance of spatial thinking and how it might be incorporated into existing standards-based instruction across all educational curricula. This report proposed
that spatial thinking be recognized as an important component of everyday life. The NRC argued that many aspects of daily life and industry require spatial thinking. This includes everything from assembly instructions for consumer products to modeling system dynamics such as ground water flow in the science industries. The report also proposed that spatial thinking become a fundamental component of K-12 education and serve as an integrator and a facilitator for problem solving. Advances in computing technologies signify the increasing availability of geospatial data, as well as data covering various events across space, land, and time. Thus, spatial thinking will most certainly play a significant role in the information based economy of the 21st century and beyond.

The National Research Council’s report suggested further ways in which to incorporate GIS software as a technology support system that could enable students to practice and apply spatial thinking. One such example included ecologists using the spatial perspectives provided by GIS to develop improved plans for wildlife management. In this example, GIS would allow the ecologists to increase their understanding of how organisms interact with each other and with their physical
environment in order to create a plausible management plan. It is clear that GIS technology will become an important future tool for professionals across many disciplines. For this reason, it is important that students in secondary schools across the nation be introduced to this technology.

Albrandi (2005), in a paper entitled "Roundtables of Environmental and Geographic Discourse: Realigning Paradigms," detailed a forum at which attendees discussed environmental education and geography and the increase in "depth and breadth" (p. 1) each discipline has attained from its original origin. Albrandi noted that these disciplines are inherently inter-disciplinary necessitating the collaboration of the two. The partnership between the two disciplines would bring together both people and perspectives from each of the domains into new networks of cooperative problem solving. Several forum attendees responded that they were introducing GIS into educational settings as a technology based education tool. At the forum the need was discussed for several entities, such as teachers and community groups, to collaborate in order to maintain sustainability and integration of GIS in classroom education. Thus, the
importance and usefulness of GIS in the classroom has already been recognized by some educators.

In the publication *Exploring Common Ground: The Educational Promise of GIS* (1995), ESRI provided a rationale for GIS in education in order to encourage and to expand the role of GIS in K-12 education. Several important reasons for the importance of integrating GIS software into education were discussed, including: GIS engages and exercises multiple capacities and intelligences; GIS can be a tool for education reform; GIS relies on and fosters a mindset of exploration; GIS promotes spatial awareness; and GIS relies on and promotes finding information and knowing what to do with it.

In “The Fourth R? Rethinking GIS Education” (2006), Michael Goodchild described the inroads GIS software has begun to make in modern life and education. Goodchild argued that, just as reading, writing, and arithmetic are part of any core curriculum, spatial thinking must also begin to be seen as a fourth component of modern education. Goodchild contended that spatial thinking “must be considered essential as much to basic functioning as to the realization of life’s higher objectives” (p. 5). He related that the number of students taking GIS courses each year in the United States is currently in the tens of
thousands and may exceed 100,000 worldwide. Students taking these courses include those headed for careers in planning and the environmental sciences. These students see GIS as a definite asset on a resume whether they eventually work in the private sector, in government, or in university research. “New employers see the value of GIS experience as more abstract and altruistic and more in line with the traditions of liberal education” (Goodchild, 2006, p. 2). GIS software is seen as something that every educated person should know about: “a set of tools that allow people to see and interact with the world in new and stimulating ways, a contemporary way of satisfying a deeply felt love of maps and geography, and a way of expressing concern for the future of the planet” (Goodchild, 2006, p. 5).

Goodchild’s “Fourth R” rationale was evident in GIS in the Classroom: Using Geographic Information Systems in Social Studies and Environmental Science (2003). In this book Albrandi presented the results of a study that examined five case studies of teachers and their students who had utilized GIS software in their education curriculum. Albrandi stated that traditional social science classrooms merely present students with the task of memorizing facts. However, Albrandi concluded that
classrooms that utilize GIS software provide students with a tool to explore, question, sift, integrate, analyze, interpret, evaluate, and act on data. Combining these processes with real world data collection in local communities allows students to connect information and build their own conceptual framework of what constitutes the solution to their posed questions. These conclusions correlated with the findings done by the National Science Foundations report on spatial awareness.

The aforementioned case studies include teachers and students in schools in Detroit, Virginia, and in the southeastern United States. All the school names and exact locations were changed, but all schools were noted as excellent magnet schools in their respective educational discipline. GIS was utilized in these schools for projects as diverse as studying local African American history to partnering with the United States Geological Survey in studying groundwater imperviousness in the local community. Teachers reported that students were more engaged in these projects.

The Northwest Center for Sustainable Resource (NCSR) issued a report entitled, Employers in Natural Resources: What they’re Telling Us (1998), outlining its program for advanced technological education. The NCSR worked with
various colleges and private corporations to develop education programs based on current and future industry needs. The introductory statement of the report focused on the increasingly important role GIS software plays in analyzing natural resource management and industry decision policy alternatives. Albrandi similarly recognized the important role of GIS software in the following statement: “to a prospective health care worker or doctor, how would not understanding the relationship between locations and conditions of population, disease, and environmental features affect the community’s public health?” (emphasis in original, 2005, p. 164). The NCSR report stressed the importance of trained GIS professionals who can reliably capture data for accurate portrayal and analysis of the information.

As part of his Master’s thesis, A Role for Geographic Information Systems in the Secondary Schools: An Assessment of the Current Status and Future Possibilities (1994), Steve Palladino conducted research on the use of GIS in secondary school classrooms. As part of the research, a pilot study to determine the roles for GIS software in classrooms was conducted. The study included a one-week workshop for secondary school teachers in which methods and ideas for GIS classroom integration were
discussed. The positive results of the pilot study resulted in an extension of Palladino’s research to include the following: the interface between secondary school geography education and GIS in the classroom; the technological environment in schools; and the potential ramifications for GIS activities. This extension led to the conclusion that GIS can play an important role in geography education. The pilot study also established that the rudimentary computer infrastructure presently found in many secondary schools limits GIS use by students.

Incorporating GIS into education curricula has become increasingly important in today’s world (National Research Council, 2006), and as case studies have shown (Albrandi, 2005), GIS is most effective in showing the limitations of data and developing critical thinking skills by encouraging students to answer the “why” of an issue rather than just the “how”. The correlation of the case study findings with modern national science standards (National Research Council, 1996) that require the integration of new technologies, and social and personal perspectives, demonstrated the need to develop spatial awareness skills in tomorrow’s workforce. It is clear that GIS software can play an important part in encouraging spatial awareness skills in students.
Several educator resources exist for incorporating GIS into the classroom. Aside from the previously mentioned literature, there are several texts that provide software tutorials, practical student activities that relate to the geosciences, and trial software packages. There also are several informational texts that include case studies and several websites that should be viewed as important resources for curriculum, grants, and support. As part of this section of the literature review several references are included, chosen based on their ease of use, relevance to environmental educators, and ease of locating. This list should not be considered comprehensive.

Websites

The inherent need to collect and analyze data in spatial thinking enables the internet to be one of the core foundations of GIS technology; therefore several websites were considered. These websites where chosen based on their relevance to GIS technology, importance in GIS research, for their use of current data sets, and future online data support potential.
ESRI, the world’s leading creator of GIS software and tools, provides an excellent educator’s webpage located at: http://www.esri.com/getting_started/education/index.html. The site acts as a resource for educators looking for texts, networking, software and software support, training, grants, and links to other websites and community events.

As part of the U.S. Geological Survey’s (USGS) Education and Communications Program, a webpage for educators has been provided and is located at: http://rockyweb.cr.usgs.gov/outreach/giseduc.html. The website provides spatial data accessible to users, a large archive of GIS lessons, posters, and web links to other resources. The site also provides examples on incorporating Global Positioning System (GPS) and Google Earth into education lessons.

Several university-affiliated GIS projects are also available. These projects provide GIS-based curriculums, ongoing projects, previous studies, spatial data, and links to other resources. These websites include the University of California, Santa Barbara’s National Center for Geographic Information and Analysis (NCGIA) located at: http://www.ncgia.ucsb.edu/education/ed.html, which aims to provide a web based resource for curriculum
building; the University of Montana’s “Spatial Sci” program which aims to provide educators with a sustained environment for the integration of geo-technologies into classroom instruction (http://www.spatialsci.net), and the University of Florida’s “Journey North” program, which uses GIS to study seasonal butterfly migrations, located at: http://nature.berkeley.edu/~alyons/jn/jnorth.html.

Texts for Classroom Use

Texts that provide the software and lessons for students to build maps, explore and analyze data, and develop solutions to environmental and natural phenomena are currently available to educators. A couple of these texts are reviewed in this subsection. The first reviewed text includes Exploring Water Resources: GIS Investigations for the Earth Sciences, one text in a series of four developed for GIS investigations in earth sciences. These texts were developed by Michelle K. Hall-Wallace (2003) and the University of Arizona Saguaro Project Team. The Hall-Wallace texts are useful for the wide array of topics and depth of information they provide. Next, Exploring Environmental Science with GIS (2005) by Stewart, Cunningham, Schneiderman, and Gold, provides several inter-related environmental science activities for students. The text is useful for educators
looking for ideas and activities in a short but concise textbook for their classroom.

Other References for Educators

The following reviewed literature includes resources replete with brief case study synopses. These resources are presented in order to provide educators with inspiration and ideas to help develop their own research projects.

Managing Natural Resources with GIS by Laura Lang (1998), is a collection of 12 case studies that establish how GIS has been used in real world situations in managing various natural resources. One mentioned case study involved the Chevron Corporation. Chevron used GIS to study how to protect surface resources by developing precise drilling locations. Another case study at Seaside High School in Portland, Oregon demonstrated how GIS investigations with local and federal resource management departments studied Oregon wetlands and watersheds to help produce solutions to local environmental issues. Another mentioned case study involved the Environmental Protection Agency who, among other projects has used GIS software to study the effects of air pollution on forests. The text also includes several website links for further research.
In Hydrologic and Hydraulic Modeling Support, David Maidment and Dean Djokic (2000) presented topics on how to deal with terrain modeling and GIS support for hydrologic and hydraulic modeling. The book is separated into three sections. The first section describes basic principles involved in the use of GIS in hydro issues and data collection. The following section provides available GIS hydro software tools and techniques to use in their application in hydro modeling. The third section presents practical applications of GIS on real world hydrologic and hydraulic issues. All the topic headings in each section of the book came from research papers submitted by various participants in the 1999 ESRI International User Conference. For educators the text will provide ideas and support for activities with students in honors or A.P. courses.

Summary

Environmental education combined with constructivist and place-based learning approaches has been shown to develop a more environmentally sensitive student (Sobel, 2004). GIS software is an excellent way to combine constructivist and place-based learning approaches. Successfully accomplishing the development of critical
thinking skills and ensuring inter-disciplinary awareness students can be best done when introducing environmental issues as real world issues for students to study and solve (Klein & Merritt, 1994).

Antoine de Saint-Exupéry said “If you want to build a ship, you don’t drum up the men to gather wood, divide the work and give orders. Instead teach them to yearn for the vast and endless sea” (1950, p. 215). Although this statement is not rooted in environmental education the same idea applies. Environmental education is a call for a citizenry that is knowledgeable, aware, and motivated to address environmental issues (Stapp et al., 1969). Relevant lesson plans utilizing GIS can support the development of an environmentally literate citizenry. The literature reviews in this chapter provide a basis for understanding the wealth of GIS resources available and their possible application to this project.
CHAPTER THREE
DESIGN OF PROJECT

This project was designed to be used either in part, or in its entirety, by educators who want to incorporate constructivist and place-based educational approaches through GIS software into secondary curriculum and integrate spatial thinking while teaching about the Santa Ana River Watershed. Courses where the project would be relevant include math, earth sciences, social studies, geography, and literature. This project is based on free downloadable ArcReader© software that allows teachers to create map environments without needing the full ArcGIS software©. Included with the ArcReader© software are easy to understand instructions and tutorials.

The developed lesson activities utilize real world environmental and human issues which seek to teach students how to understand the inter-relatedness of various disciplines (see Appendix A). Educators are invited to fill in lesson gaps with relevant information that would be useful to the lesson activities. In order to accomplish this, several extensions were incorporated in the developed lesson plan to allow educators to select activities in order to easily expand the lessons. All
Lesson activities were developed as teacher guides and answers provided to activity questions. Educators may reference Table 1 for correlations of the lessons to application of spatial thinking development as well as how the lessons utilize to the constructivist approach.

The GIS lesson plan resources consulted for this project were chosen based on relevance to environmental or earth science issues, clarity of writing, software instruction, and applicability to secondary science standards. Map data sets and information used in the lessons were obtained from local government agencies, USGS, and the Santa Ana Watershed Project Authority. When possible, the most current data available were used. All activity data files and published maps are included on Compact Disk (see Appendix C).

Educators in the Santa Ana River Watershed will find the use of local data as well as the place-based educational approach as the applicable and relevant to their lesson plans. All lesson activities in the project were correlated to the National Research Council’s National Science Education Standards (see Appendix B).

The status of GIS software is constantly evolving because of new software, technology, and research. As extensions, educators can have students obtain more recent
versions of GIS software and data as well as further their study in ArcMap© applications.

For the language arts connection, students are asked to print maps and keep a class journal. A journal is an excellent way to develop ideas for future assignments as well as to build a record for future reference. Students are encouraged to create and display maps for others to see and use.

ArcReader© 9.2 is the GIS software package used in the activity lessons. Environmental Systems Research, Inc. (ESRI) provides the software free of charge. Before using any of the lessons educators must first visit the ESRI website and download the software. This can be done at: http://www.esri.com/software/arcgis/arcreader/index.html. Free downloadable tutorials and further instructions can be found at: http://www.esri.com/software/arcgis/arcreader/download.html. ArcReader© 9.2 for Windows runs on Windows 2000, Windows XP (Home Edition and Professional), and Windows 2003. Educators must register with ESRI before downloading; this information is used by ESRI for software tracking and software updating.
Table 1. Identification of Spatial Thinking Applications and Constructivist Approaches in Geographic Information Systems Lessons

<table>
<thead>
<tr>
<th>Lesson</th>
<th>How develops spatial thinking</th>
<th>Why constructivist approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Helps students conceptualize why natural objects exist in certain locations. Examples include watershed boundaries and river locations.</td>
<td>Each step builds on what constitutes a watershed. The addition of Carbon Creek requires students to ask questions beyond initial watershed boundaries.</td>
</tr>
<tr>
<td>2</td>
<td>Students visualize natural and human processes and their effects on the watershed and how they are related. Examples include ground water flow and precipitation.</td>
<td>Students must research and build on the different aspects of the water cycle and apply understanding to how a different area of the watershed can have a different water environment.</td>
</tr>
<tr>
<td>3</td>
<td>Students must take into account various land attributes and how they affect the whole area when planning land use development.</td>
<td>Students must apply knowledge from previous lessons as well as build new GIS skills in order to understand why specific attributes must be taken into account in real world land use issues.</td>
</tr>
</tbody>
</table>
CHAPTER FOUR
IMPLICATIONS FOR EDUCATION

The included lesson plans were chosen and developed based on their relevance to core subject areas such as math, science, social studies, English. Lesson plans were also developed in order to address the inter-disciplinary nature inherent in environmental education by drawing on place-based learning approaches and relating natural and human made aspects of watershed dynamics.

Lesson plans were designed to enable students to develop meaning through a constructivist approach with information from various educational disciplines, such as science and social studies to easily build upon the concepts. By developing activity extensions that take place outside the classrooms teachers are provided with the opportunity for incorporating place-based learning into the education curriculum. With the emerging importance of incorporating spatial thinking into the classroom (National Science Foundation, 2006), lesson activities were developed based on the ease of integrating GIS software.

The curriculum for the project was developed using data relevant to educators within the Santa Ana River
Watershed in Southern California. However this curriculum would be useful if used by teachers at secondary schools located in other Southern California watersheds. Since the majority of concepts deal with semi-arid watersheds the lessons can be adapted to local watersheds throughout the southwest United States, enabling students to make the relevant connections to their local geographic community. For educators the importance of the project is as a demonstration of how available GIS software can be used to ensure place-based education and assist with the development of critical thinking skills.
APPENDIX A

LESSON ACTIVITIES
Santa Ana Watershed

Objectives

Students will
- Identify the different characteristics of watersheds.
- Evaluate the role of watersheds in the environment.
- Learn basic ArcReader© GIS skills.

Subjects

Earth Sciences, Life Sciences, Art, Language Arts.

Methods

Students are presented with a published ArcReader© map along with a selection of objects to investigate and discuss as natural components of a watershed.

Background

Watersheds are regions of land where all the water drains downhill into a body of water such as a lake, river or ocean. These sources of water include rain, snow, wet meadows, swamps, rivers, marshes and groundwater. Watersheds are separated from each other by areas of higher elevation called ridge lines or divides. Viewed from above watershed drainage patterns have a branch-like appearance, similar to branches of a tree with the smaller twigs flowing into the larger branches and then the main trunk.

The Santa Ana River watershed is located in southern California, south and east of the city of Los Angeles. The watershed includes most of Orange County, the northwestern corner of Riverside County, the southwestern corner of San Bernardino County, and a small portion of Los Angeles County. The watershed is approximately 2,800 square miles in area, or about the same size as New Jersey and Delaware combined. The highest elevations of the watershed occur in the San Bernardino Mountains (San Gorgonio Peak, 11,485 feet in elevation) eastern San Gabriel Mountains (Mt. Baldy, 10,080 feet in elevation), and the San Jacinto Mountains (Mt. San Jacinto, 10,804 ft). Further downstream, the Santa Ana River flows through the Santa Ana Mountains and the Chino Hills before flowing into Orange County and into the Pacific Ocean. The demands for water in the watershed are large. The watershed has a rich agricultural history, large concentrations of citrus, dairy, and industrial/commercial areas. The 2000 census indicated that the watershed is home to 4.8 million people, or about the same as the entire state.
of Colorado. The watershed is also home to many wildlife species, including several that are protected by the Environmental Protection Agency (EPA) such as the Santa Ana Sucker Fish and the San Bernardino Kangaroo Rat.

**Activity 1**

Have students navigate to the disk drive on their computers and open the ArcReader© program “Santa Ana Watershed.”

The ArcReader© Window opens and provides a view of the watershed. ArcReader© can open published mapfiles (.pmf) that have been created in ArcMap© and ArcGlobe© with the ArcGIS© Publisher extension.

Students will begin by becoming familiar with several of the software tools.

The table of contents lists the map layers grouped in data frames. A data frame is a frame that groups the layers you want to show on your map. By checking or un-checking the layer boxes, layers become active or inactive. Each layer references all the data that can be viewed in the map. This map references the Santa Ana Watershed and shows the lakes, rivers, mountains and cities within its boundaries.

The data toolbar contains all the tools to move around the map and to display map features. Students can get additional information on each tool by pressing the help button or Shift + F1 on your keyboard while pointing at the tool icon. You should also take the time to explore what each of these tools does.
The map display shows all the layers that are active in the table of contents.

1. Have students click the identify tool. An identify dialog box will appear on screen.

2. Next, students should move the pointer over and click on the large lake near the city of Corona in the center portion of the map display.

3. The dialog box now displays all the information associated with the Prado Dam lake layer. Scroll down the bar on the right of the dialog box until you reach the thunder bolt symbol and click on it. This will open the students' web browser and connect them to the Army Corp of Engineers, Prado Dam website. Several of the features in the map can be further explored in this manner.

4. Have students click on the view icon at the top of the screen and scroll down to the bookmark tab and click on Sub Basins. This will automatically zoom in to a pre-assigned view. In this case it is two small sub basins in the San Bernardino area of the watershed. Students should also turn on the Sub Basins layer in the table of contents.
5a. Next Click on the Draw tool.

5b. Students should trace the sub basin boundaries in the map display. Sub basins are smaller watersheds that make up a larger watershed. What are the reasons behind the location of these particular sub basins?

Answer:
The sub basin boundaries are the specific canyon walls. All the water in each canyon drains to the smaller river in the canyon bottom. These smaller rivers in turn drain into the Santa Ana River, making them part of the Santa Ana Watershed.

5c. Have students turn off the sub basins layer and use the eraser tool, found next to the draw tool in order to clear off the sub basin boundaries that were drawn. Have students click on the view extent tab. This will take them back to the Santa Ana Watershed view.


7. Students then should use the draw tool to highlight the river stream paths along the watershed. Students should choose a different color and draw arrows showing the direction the river is flowing. What shape do the highlighted areas look like? Notice all the streams and rivers appear to flow towards the Santa Ana River and then the ocean. Why?
Answer:
There are various answers some examples are the shapes look like branches on a tree or blood veins in a body.

All the water flows to the Santa Ana River due to topography. The most north-eastern areas of the watershed are located in the highest elevation zones. All the water in the watershed flows downhill to the Santa Ana River, which follows the low points in the topography. Teachers should note these low points are being carved out by the river itself.

8. Look at the Carbon Creek highlight that was drawn. Have students click on the bookmark and click on the pre-assigned Carbon Creek view. Why does Carbon Creek appear to be the only river not flowing to the Santa Ana River. Why is it included as part of the same watershed?

Answer:
Carbon Creek originally flowed to the San Gabriel River, but the natural flow of the creek was diverted away from the San Gabriel in 1960 due to the construction of Carbon Creek Dam and Channel. Carbon Creek flow is now directed towards the Santa Ana River to be used as groundwater recharge. When storage basins are at full levels Carbon Creek is re-diverted towards the San Gabriel River.

Discussion Questions

While exploring various attributes, discuss with students the various components that make up a watershed.

Students should identify why a watershed has specific boundaries. How do these boundaries affect water flow in the watershed? How might these boundaries change over time?

Answer:
Watershed boundaries are often composed of high points in the surrounding elevations that cause all the water to flow to a specific point.

These high points can change over time due to natural forces such as weathering and erosion or by human built structures such as dams and diversion channels.

What other watershed attributes could have been included within the map display? Why?
Answer:
Other attributes could have included human-made objects such as pipelines and dams as well as natural objects such as small streams. Additionally the watershed could have been broken up into smaller sub basins.

What human-made objects can students identify within the watershed that may have altered the natural state of the watershed? What other human-made objects not included in the map display may or may not change the characteristics of a watershed?

Answer:
These objects are similar to the above answers.

How do animals and plants fit within the framework of the watershed?

Answer:
All plants and animals, like people, require water for life. Hence, they are a part of the larger watershed ecosystem.

Extensions

Students should link to the various websites included in the maps and further research the importance and role of watersheds.

Students can navigate to the ArcReader tutorial included with the software in order to further explore the capabilities associated with the software.

Invite students to explore other published ArcReader maps available at www.arcgisonline.esri.com.

Students should begin a journal describing various published maps they find on the internet and how the maps are useful in their studies. As part of the journal assignment students can print and display various maps they find.

Resources

ESRI, http://www.esri.com

Water Cycle

Objectives

Students will
- Identify characteristics of the water cycle,
- Understand the inter-relationships of surface water, groundwater, rain water, and how they affect people.
- Become familiar with human-made structures created to supplement water resources.

Subjects

Math, Earth Sciences, Language Arts

Methods

Students are presented with a published ArcReader© map along with a selection of objects to investigate, analyze and discuss as natural and human-made components of the water cycle.

Background

Water can be found throughout the world in various forms and amounts. As it travels throughout the world in various forms, it is part of the water cycle (Figure 1). The total amount of water calculate to flow into and out of the water cycle in a specific area, including human made and natural systems, is referred to as the water budget.

Processes that drive the water cycle are evaporation, condensation, and precipitation. These processes are primarily driven by gravity and solar energy. They convert water to vapor which raises water into the atmosphere where it condenses into precipitation and falls to the ground. Gravity then controls the downward flow of water through the watershed.

Precipitation is the process where water by vapor in clouds is returned to the Earth's surface either as liquid drops (rain) or as solid particles (snow, hail).

Evaporation is the process where by liquid water is changed to vapor and returned to the atmosphere. The total loss of water in the watershed due to evaporation is described as evapotranspiration.

The downward flow of water through streams and rivers is called surface run-off flow. Water flowing across parking lots, streets and other human made objects is also included in surface run-off flow.
Water flow can also occur underground through fractures in rock or in between the tiny pore spaces between sand particles. The size of the spaces in an underground medium is referred to as its porosity. A bounded area containing water underground is called an aquifer.

In some instances people have created systems such as dams, basins, pipelines and pumps in order to divert, control and store water for the beneficial use of people.

Figure 1.

Activity 2.1

Have students navigate to the disk drive on their computers and open the ArcReader© published map (.pmf) titled “Water Cycle.”

The Santa Ana Watershed is largely located in a semi-arid Mediterranean climate. This climate is characterized by long, hot, dry summers and shorter wetter winters. In this climate the evaporation each year totals more than the precipitation. How might this affect local water supplies?
Answer:
With more water leaving than entering the watershed plants and animals have to adapt to small water supplies. If more water is needed by the living organisms in the watershed than is available a decrease or drought the in water supply can occur.

1. Turn on the Rainfall Layer in the layer box. This layer represents modeled monthly average precipitation totals received for different regions in the watershed. Each region is represented by a different color.

2. Have students click on the identify tool.

3. Have students select the purple region that runs along the north central portion of the map display.

4. In the identify box that appears have students scroll down and look at the InPerYr box. This total represents the average amount of rain in inches per month that falls in the selected area. Does this number seem high, low or about right, Why? Try selecting different areas. What totals are shown? Why do the different areas have different amounts of precipitation? How do mountainous areas compare with coastal regions. Why?

Answer:
The totals are about right for a semi-arid desert region. Compare the totals in the layer to the average yearly precipitation totals in a rain forest which average 60 inches per year.

The different regions have different precipitation rates due to changes in elevation, temperature and humidity levels.

As moist air collides with mountains, it is forced to rise. As this occurs, it cools and condenses to form clouds and allows moisture to escape. This process, called orographic rainfall, leads to precipitation rates higher than along coastal areas.
2.2

5. Click on the View tab and scroll down the list to the bookmarks section and click on Bunker Hill. This is the Bunker Hill sub basin within the Santa Ana Watershed.

6. Turn on the groundwater basins layer and turn off the precipitation layer. This layer shows the boundaries of the Bunker Hill area as well as other sub basins in the area.

The USGS estimates the average total surface run-off flow of river water into the basin to be 15,000 acre-ft per year (af/yr). One acre foot is enough water to cover one acre of land one foot deep or 43,560 cubic ft per year. Students should imagine a swimming pool about the same size as a football field filled to one foot deep. The amount of surface river water leaving the basin is 6,600 af/yr. Calculate the difference in the amount entering the sub basin and the amount leaving? Where do you suppose the difference is going?

**Answer:**

A large part of the difference infiltrates into the groundwater aquifer. Portions are also captured in lakes and reservoirs. The use of human and agriculture water consumption also accounts for a portion of the water that does not leave the area.

The USGS estimates the average yearly precipitation in the basin to be 1.47 ft/yr and the recharge to the aquifer to equal 5% each year. Using the identify tool to determine and record the area of the Bunker Hill sub basins, multiply the area by the average precipitation to determine the precipitation volume for the basins.
Next calculate how much recharge occurs in the aquifer each year by multiplying the precipitation volume by 0.05%, and add the totals of together. Write your answers in Table 1.

<table>
<thead>
<tr>
<th>Name</th>
<th>Average Precipitation (ft/yr)</th>
<th>Area (sq/ft)</th>
<th>Precipitation Volume (af/yr)</th>
<th>Recharge Volume (af/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bunker Hill I</td>
<td>1.47</td>
<td>66575592</td>
<td>748</td>
<td>37</td>
</tr>
<tr>
<td>Bunker Hill II</td>
<td>1.47</td>
<td>277017059</td>
<td>3116</td>
<td>155</td>
</tr>
<tr>
<td>Totals</td>
<td>1.47</td>
<td>343592651</td>
<td>3864</td>
<td>193</td>
</tr>
</tbody>
</table>

Table 1.

Does this total seem like a lot? Why or Why not?

Answer:
This is a small amount of recharge to the aquifer in relation to the overall size of the aquifer. This is largely due to evapotranspiration rates as well as from human changes to the landscape, such as streets and buildings that do not allow water to infiltrate into the ground.

The precipitation rates given by the USGS differ from the precipitation rates given as part of the rainfall layer. What would account for this difference?

The Rainfall Layer is a computer generated model layer composed of the average precipitation rates between the years 1971 – 2000. These values are compared to the USGS rates which are directly measured values and more accurate.

2.3

In 1960 the voters of California authorized the construction of the State Water Project (SWP). Through the use of dams, diversions, power plants and pipelines the SWP was designed to deliver water to the residents of California for a variety of reasons, including municipal use, agriculture, recreation and enhancement of habitats for fish and wildlife.

7. Turn off the Ground-water and Rainfall layers.
8. Turn on the Recharge Basins, Watershed Dams, and Pipelines layers. These layers represent the man-made structures created to provide an additional supply of water to the watershed.

Have students explore the layers in order to see how extensive the system is.

U.S. Census data estimate that each person uses up to 232 gallons of water per day. With the total number of people in the Bunker Hill area at about 230,000, calculate how much water is needed each day to supply the area. Next convert the daily figure into af/yr to get the yearly total, write your answers in Table 2.

<table>
<thead>
<tr>
<th>Bunker Hill Population</th>
<th>Gallons/per/day</th>
<th>Total</th>
<th>Average Total Water</th>
<th>Difference Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>230,000</td>
<td>232</td>
<td>53,360,000</td>
<td>78,522</td>
<td>18,788</td>
</tr>
</tbody>
</table>

Table 2. Solutions
Conversion from gallons to acre feet = 
\((53,360,000 \text{ gal/day} \times .1336 \text{ cubic feet/365 days}) / (43560 \text{ cubic feet}) = 59,734 \text{ af/yr} \)

\[78,522 - 59,734 = 18,788\]

If the average total inflow into the basin is 78,522 af/yr, is there enough water to supply the Bunker Hill area? Refer back to Table 1, if you subtract the total ground water recharge value from the difference value in Table 2, is there still enough water?

**Answer:**
Yes, the 18,722 af/yr is the surplus generated after meeting the water needs of the Bunker Hill area. There will also be enough if you subtract the ground water recharge total which leaves you with 18,529 af/yr.

What do you suppose happens to the difference? Does it seem likely the entire watershed has the same amount of water supply and usage levels?

**Answer:**
As discussed earlier a portion of the excess recharges the groundwater aquifer, with other portions providing water to plants and animals in the area.

After having spent time answering the last questions, does the large size of SWP system seem justified?

**Answer:**
The Bunker Hill basin is somewhat unique in the Santa Ana River Watershed in that there is an excess supply of water. This is largely due to unique geologic and atmospheric conditions in the area.

As was presented earlier the population of the Santa Ana Watershed stands at around 4.8 million people and is expected to grow. This requires a large stable supply of water, justifying the SWP.

**Extensions**

Have students use the identify tool and click on the purple rainfall layer from Activity 2.1 and scroll down to the California Department of Water weblink. Students should explore the site and look for current precipitation rates for the area. Why might these values differ from the values in the rainfall layer?
Answer:
As discussed earlier this is due to the website values being measured and the rainfall layers values being calculated.

Have students research the population and water supply totals for various other parts of the watershed and calculate the water budget for each. Students should then compare the values with the earlier values calculated from the Bunker Hill area.

Answer:
Students will find most other areas have larger populations and smaller water supplies.

Resources


Bioswales

Objectives

Students will:
- Identify characteristics of Bioswales.
- Become familiar with “Green” approaches to land management.
- Become familiar with the spatial analysis capabilities of GIS.

Subjects

Earth Sciences, Language Arts, Engineering

Methods

Students are presented with a published ArcReader© map along with a selection of objects to investigate, analyze and discuss as part of a human made Bioswale.

Background

Managing landscape surface water run-off typically involves constructing concrete drainage canals (Figure 1). These canals while effective are not always friendly to the surrounding environment. Recently more environmentally friendly approaches, or green approaches, to managing surface water run-off have introduced the use of Bioswales.

Figure 1. Concrete diversion canal.

Bioswales are landscape objects designed to remove pollution from surface runoff water as well as to direct the flow of surface water runoff towards catchment basins during rainstorms or snow melts. They consist of a swaled, or long narrow trough like depression with gently sloped sides, filled with vegetation, compost and gravel. The water’s flow path, along with bioswale, are designed to increase the time water spends in the swale, which increases the trapping of pollutants and increases the percolation rate of water.
Depending upon the topography of land available, a bioswale may meander (Figure 2) or follow an almost straight channel path.

![Figure 2. Uncompleted Bioswale.](image)

Important reasons for the use of bioswales include; a less environmentally intrusive form of managing surface water runoff, bioswales used around parking lots (Figure 3) prevent large amounts of automobile pollution collected by the asphalt from being drained by rainstorms by treating and directing the water runoff before releasing it to a catchment basin or storm sewer.

![Figure 3. Bioswale between parking lots.](image)

In the fall quarter of 2007, California State University of San Bernardino (CSUSB) experienced flooding due to rains. The flooding caused roughly 4.8 million dollars worth of damage as well as causing the temporary closing of several university classrooms, buildings and museums (figure 4).
Activity 3

The following activity utilizes layers created using ArcGIS© 9.2 software. These layers can not be created using ArcReader©, however students will be provided methods behind their creation and will explore the layers in ArcReader©.

Have students navigate to the disk drive on their computers and open the ArcReader© published map (.pmf) file "Bioswales."

Using the spatial analyst tool in ArcGIS a proposed route for the construction of a bioswale was derived. These routes were based on the slope of the land, the location of storm drains and basins, the locations of flood damage during the fall 07 storm and the imperviousness or non-imperviousness of the campus to water infiltration.

Students should become familiar with the various aspects of the Bioswales published ArcReader map.

1. The various polygon shapes represent the building footprint locations on campus.
2. Students should explore the Hill-shade raster layer created from the CSUSB 1m DEM. Raster layers are basically giant tables consisting of rows and columns where each cell is assigned a different value. Rasters can be image files or can be assigned special values to indicate specific meaning such as land use or water flow paths. The hill-shade raster displays the topography of the CSUSB campus.

3. Students should note that the map layers are placed in several groups. By clicking on the group layer students can explore the various sets of data used in each group layer.

4. The suitability layer represents the suitability of a given area of the campus for the construction of a bioswale, the higher the value the greater the suitability for a bioswale. The suitability layer is a composite raster derived from: the distance to areas that received damage due to floods, the distance to catch basins and curb inlets, land use based on water impervious surfaces (buildings, pavement) and non-impervious surfaces (grass, dirt), and on the topography and the direction the surface water flow was most likely to take. Each attribute was assigned a separate weight value, (staying away from areas prone to flood is more important than being near to a curb inlet), and then added together to form the suitability layer.

What other land surface attributes might be taken into consideration for a more detailed land use suitability layer?

Answer:
Possible answers include more detailed source data, this would include; level of imperviousness (such as types of soils and vegetation), surface water run-off flow rates, higher precision of slope measurements and rain water probability models to assess the size of water the bioswales may have to hold.

The constraints layer represents a raster layer calculation of the suitability of land for a bioswale and its relation to impervious and non-impervious
surfaces. Cells with a lower value, or lighter color, represent the areas that have the least constraints for building a bioswale through.

What other attributes could be included for a more accurate constraints layer?

**Answer:**
Possible answers include more accurate raster data sets, such as suitability and land use rasters. Cost of changing existing objects in the landscape, it is more expensive to build a bioswale through concrete than through grass, and it may be less expensive to build through an area that is undeveloped.

Under the view tab students should go to the bookmark *suitability* in order to obtain a more detailed view.

1. Students should open the *proposed bioswale catch basin* group layer and the *proposed bioswale route* group layer.

2. Students should turn on the suitability layer.

3. The map includes several proposed catch basin locations for bioswales. These locations were chosen based on the most suitable areas displayed in the suitability layer.

What other areas might have been suitable for a catch basin?
Answer:
Any area with a high suitability value. However students should note that conditions on the ground may not make for ideal basin locations. For example the suitability layer shows areas in the parking lots would be suitable for a catch basin, this may be true but a large cost would be incurred converting a paved area into a catch basin.

4. Using spatial analyst tool in ArcGIS© proposed route for construction of a bioswale were derived. These routes were based on a least cost approach which included slope of the land, location of storm drains and basins, the locations of flood damage during the CSUSB fall, 2007 storm. The imperviousness or non-imperviousness of the campus to water infiltration was calculated using data obtained from CPDC showing where concrete and non-concrete areas were located.

5. Students should note that some proposed route paths travel through building footprints, obviously making them infeasible. Why might this have occurred?

Answer:
The reliability of the model is largely based on the accuracy of the data. These route paths demonstrate the lack of detail in the data or possible flaws in the methods used to analyze the data. Teachers should stress the importance of collecting the most detailed data sets possible as well as the importance of excluding method flaws through trial and error when analyzing data. Attention to detail is important when undertaking any research project.

Extensions
Students should explore turning on and off various layers for creating maps suitable for printing under the Layout View.

Students should research local environmental issues and develop ways in which GIS software can be used to help analyze the situation and provide possible solutions.

ESRI provides grants for free software, hardware and training bundles for classrooms under their Community Atlas program. Educators should visit www.esri.com/grants/esri/education for further details on expanding GIS in the classroom.

Resources
CSUSB. Capital Planning, Design and Construction.
http://www.cpdc.csusb.edu
APPENDIX B

RELEVANT STANDARDS AND CORRELATIONS
Standards and correlations based on National Research Council's National Science Education Standards, chapter 6, Science Content Standards 9-12.

Science and Technology

CONTENT STANDARD E: As a result of activities in grades 9-12, all students should develop

• Abilities of technological design
• Understandings about science and technology
• Science often advances with the introduction of new technologies. Solving technological problems often results in new scientific knowledge. New technologies often extend the current levels of scientific understanding and introduce new areas of research.
• Science and technology are pursued for different purposes. Scientific inquiry is driven by the desire to understand the natural world, and technological design is driven by the need to meet human needs and solve human problems. Technology, by its nature, has a more direct effect on society than science because its purpose is to solve human problems, help humans adapt, and fulfill human aspirations. Technological solutions may create new problems. Science, by its nature, answers questions that may or may not directly influence humans. Sometimes scientific advances challenge people’s beliefs and practical explanations concerning various aspects of the world.

Science in Personal and Social Perspectives

CONTENT STANDARD F: As a result of activities in grades 9-12, all students should develop understanding of

• Personal and community health
• Population growth
• Natural resources
• Environmental quality
• Natural and human-induced hazards
• Science and technology in local, national, and global challenge
APPENDIX C

COMPANION CD
REFERENCES


