Advancing STEM Education with GIS

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Introduction

By Tom Baker, Esri Education Manager

Science, technology, engineering, and math (STEM) education is a multidisciplinary approach to improving education, the work force, and national competitiveness. President Barack Obama noted that "Strengthening STEM education is vital to preparing our students to compete in the twenty-first century economy, and we need to recruit and train math and science teachers to support our nation's students." (White House Press Release, September 27, 2010).

Why is STEM important?

High-quality STEM education directly supports STEM-based careers and, collectively, a work force that is more globally competitive. STEM education requires effective curriculum standards, high-quality teacher preparation, and support for national policies and frameworks.

Central to global competitiveness and economic development, STEM careers are at the forefront of innovation and are stable, lucrative, and rapidly growing. "Technological innovation accounted for almost half of US economic growth over the past 50 years, and almost all the 30 fastest-growing occupations in the next decade will require at least some background in STEM."

- At all levels of educational attainment, STEM job holders earn 11 percent higher wages compared with their same-degree counterparts in other jobs.

- Over the past 10 years, STEM jobs grew three times faster than non-STEM jobs. STEM jobs are expected to grow by 17 percent during the 2008–2018 period versus 9.8 percent growth for non-STEM jobs.

- In 2010, the unemployment rate for STEM workers was 5.3 percent; for all other occupations, it was 10 percent.

STEM education is about robust and coherent STEM curriculum and experiences that are multidisciplinary, integrative problem-solving inquiries that foster critical and computationally driven thinking. It is about engaging students with real data in real problems that are approached creatively and collaboratively, the way professionals need to work. More broadly, the STEM education initiative is also about ensuring an adequate supply of highly qualified and effective STEM teachers.

How does GIS enhance STEM learning?

Geographic information system (GIS) technology can engage several critical elements in STEM curriculum and instruction. GIS tools and techniques lead to understanding cross-disciplinary phenomena and solving problems rooted in academic and real-world concepts. People use GIS to make maps, analyze data, and decide on best solutions. From a curricular perspective, GIS allows us to study climate change, design cities, inventory geologic samples, plan ecological growth models, catalog contents of an archaeological site, and countless other activities. GIS and related geospatial technologies of global positioning systems (GPS) and remote sensing can be used to simultaneously engage students in science, technology, engineering, and math.

Instructionally, GIS is well suited to driving problem-based learning (PBL), an approach to classroom inquiry that is guided by a question, with students collecting data and making analytical conclusions. PBL and inquiry are specifically suggested by the National Science Education Standards as instructional frameworks best suited to support deep, meaningful learning. GIS allows students to collect and visualize authoritative data about the question of interest, adding their own data to the map before performing a wide range of analyses on the data in question. GIS problems are steeped in both critical thinking and spatial thinking elements, motivating learners as they learn work force-ready skills. In short, GIS allows STEM students to do exactly what STEM professionals do in thousands of career fields daily.

Advancing STEM in Formal Education with GIS

Combining Math, GIS, and Community Service

Teacher Inspires Students to Use GIS to Solve Real Problems

By Steve Obenhaus, Olathe North High School

Steve Obenhaus, a math teacher at Olathe North High School in Olathe, Kansas, has proved that you do not need extensive GIS training to effectively and meaningfully integrate geospatial technologies into a high school curriculum.

Integrating GIS in secondary curricula is a relatively new concept. Finding an approach that will hold students' short- and long-term interest can be difficult. Obenhaus has succeeded in incorporating GIS in his math courses and has helped his students produce high-quality GIS projects.

Students in the school's Distinguished Scholars program spend one hour per day during their senior year completing a senior project. This program offers students individualized lesson plans in a specific discipline. Since Obenhaus and another teacher introduced GIS to the school, student scholars in geoscience, biotechnology, and math have used GIS in their projects.

Obenhaus has a simple approach: ask a question about something that is bothering you and use GIS combined with math to answer the question. "I teach math, which is more of a tool than a subject," explained Obenhaus. "By combining GIS and math, students use both tools to answer spatial questions about the world. Only with GIS can they quickly perform multiple

analytic functions and see spatial patterns that are not apparent with a graph or table."

Obenhaus and former student Elizabeth Vidaurre test water at one of the newly built wells in Haiti.

His official GIS training was a two-week institute at a local university. Most of his GIS training has been informal. "I realized that GIS is very flexible. I played around with it and realized it could be used in so many ways in my classes. You don't need six months of training to have students do simple projects," said Obenhaus.

When questions arise that he cannot answer, Obenhaus challenges students to figure out the answers before he does using ArcView online help. When questions cannot be answered using online help, Obenhaus calls on city and county GIS professionals who help. Some local professionals come into class. According to Obenhaus, students really enjoy learning from people who use GIS in their career.

In Obenhaus' classroom, the first step in creating a project is having the students think spatially about a problem. He says that coming up with a question is the easy part, because most problems have a spatial component. "I learn from others' examples, so when I find good data online, I think about a question students can answer with it. When I see how professionals solve problems, I start to see the possibilities of what can be done in my own community." This year, his students are collecting data about the water quality of a local stream before, during, and after a construction project. They are using GIS to look at changes not only along the length of the stream but also over time.

His next step is helping students figure out a problem-solving approach that combines math and GIS. Students learn the basic functions of ArcView during in-class lessons taken from the Esri Press book series Our World GIS Education. These textbooks include interdisciplinary GIS lesson plans for different academic levels. Once students have a basic understanding of GIS, they stop working on prepared lessons and start working
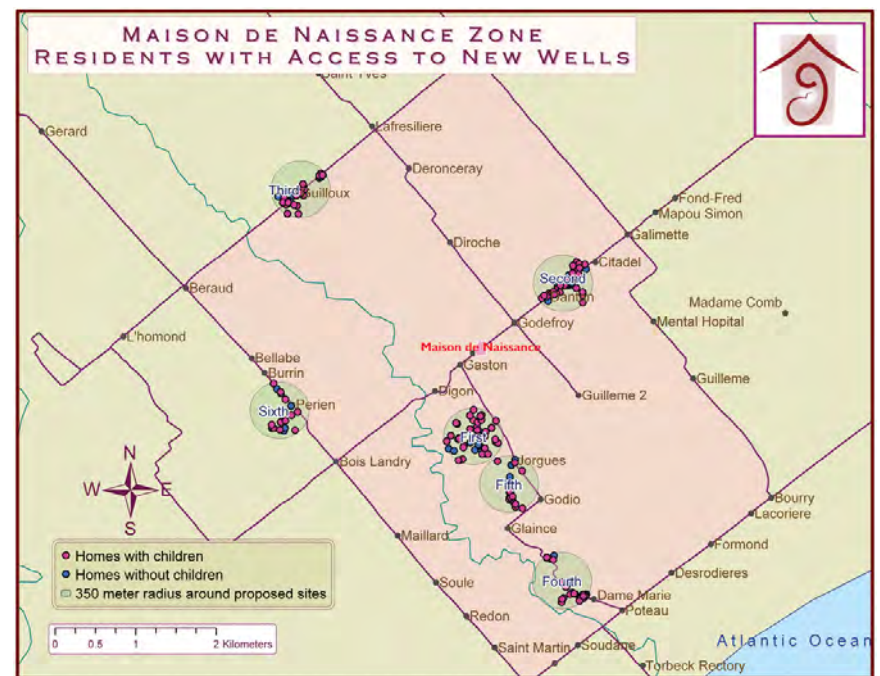
With help from a Kansas GIS professional, Vidaurre used ArcView to identify the highest clusters of children without access to clean water. With this information, she located six new wells where they would benefit the greatest number of children.

on independent projects. In these projects, they ask a spatial question and find the data needed to answer it.

Obenhaus gives students the necessary tools, GIS training, a question, and an approach to problem solving. Then he lets students figure out a solution. "They pick up GIS really quickly when they play with ArcView during their own project, learning by trial and error," said Obenhaus.

There is a common thread in his students' projects. In addition to answering a spatial question, students have followed Obenhaus' philanthropic example and worked on projects that serve communities, whether these communities or local or half a world away.

Obenhaus and his wife do volunteer work for a maternity and neonatal clinic, Maison de Naissance, in a rural area of southern Haiti. The clinic's mission is to decrease maternal and infant mortality rates in an area with extreme poverty.

Water-based diarrheal diseases are the leading cause of infant mortality in the developing world. When the clinic received funding to build wells to give more families access to clean water sources, the clinic director asked Obenhaus if he and his students could locate these wells.

He agreed. When he began the project, Obenhaus had little knowledge of water testing and locating water sources. He began by asking a water analyst how to test water quality. He then traveled to Haiti with donated supplies and trained Haitians to test the water.

This work was assisted by one of Obenhaus' students, Elizabeth Vidaurre, who went on to develop her own related project. A distinguished math scholar at Olathe North High School, Vidaurre combined her math and GIS skills in a senior project for determining how to select well locations that would benefit the greatest number of children in need.

The water testing results, combined with the clinic's records on the number of children and where they live, were the basis for Vidaurre's research project. "We had two unique data layers that no one else had," said Obenhaus, who had students use ArcView to create basemaps from the data.

"At first I thought it would be like playing a computer game, but it was serious work to use GIS," said Vidaurre. "It's a tool that helps you solve real problems. I could have done the project without GIS, but it would have taken much longer to analyze data and would not have been as accurate."

With help from a Kansas GIS professional, Vidaurre used ArcView to create buffers around the homes of families living more than 350 meters from a clean water source. With this information, she analyzed where the highest clusters of children without access to clean water were located.

The project was successful, but it took a few attempts to get it right. Obenhaus and Vidaurre worked together to find a quantitative approach for locating wells. Vidaurre ran chi-square tests to first determine if access to a deep-drilled well was an advantage. She found there was an advantage: the data showed a strong correlation between the presence of E. coli and hand-dug wells and open springs. By finding the best location for six wells, 1,180 children in need would have access to clean water.

In developing countries, children often do most of the water collection. Closer access to safe water not only improves their health but also gives them greater opportunities to attend school.

"Because of learning GIS, writing the paper, and presenting the results, I feel more prepared for life," said Vidaurre. "As a high school senior, I was networking with CEOs to fund-raise for my project. It helped me feel more confident as an intern working at a health systems IT company." The CEO and others were impressed by her project and, during her summer internship, had Vidaurre present ways GIS could benefit their company.

Presentations about her work in Haiti not only resulted in donations for her project but made her a recipient of the Spirit of Philanthropy Youth award from the Association of Fundraising Professionals (AFP).

After graduation, Obenhaus brought Vidaurre to Haiti to see the results of her work. Looking back on the experience Vidaurre said, "I have traveled in Latin America, but I had never seen a country that was so underdeveloped. I saw babies who were malnourished and kids with bellies bloated from worms. It was important to me to see the places I mapped and meet people. It wasn't just about wells, because personal experiences and new relationships remain most important to me."

Obenhaus keeps Vidaurre, who is now a junior at the University of Rochester, up-to-date on the latest work done at Maison de Naissance. Difficulties in gathering data have made it difficult to show a decline in rates of pediatric water-related diseases. Nonetheless, Dr. Stan Shaffer, director of Maison de Naissance, sees the work of Obenhaus and his students as beneficial.

"In poor communities, such as the villages of rural Haiti, it is critically important that health needs be carefully defined so that critical resources can be targeted for their highest impact," said Shaffer. "Steve and students such as Liz are demonstrating how mapping is an essential tool for organizing health information. You wouldn't attempt microbiology without a microscope, so it's not surprising that Steve Obenhaus says that we shouldn't attempt community health work without good maps."

Obenhaus' students continue working on the wells project. For example, they found that not only were new wells needed, but old wells had to be repaired. The latest student projects look at other health-related issues such as what happens to the quality of water once it leaves a well. Students found that just because water is clean at its source does not mean people drink clean water, so they are now trying to figure out how collection and storage methods affect water quality.

Obenhaus, who is clearly an inspiration to his students, downplays his influence. "It's easy to look good when you are surrounded by smart kids who work really hard to make a difference in the world," said Obenhaus. "To me, this is not work, it's fun." In 2007, Obenhaus was selected at the state level to receive a Presidential Award for Excellence in Mathematics and Science Teaching.

Obenhaus' teaching approach can be replicated for advanced placement human geography, math, community service programs, and other courses, both traditional and nontraditional.

(This article originally appeared in the Spring 2009 issue of *ArcUser*.)

Texas Students Use GIS to Track H1N1 Flu

By Penny Carpenter, Byron Martin Advanced Technology Center, Lubbock Independent School District

Last April, when the spread of H1N1 (swine) flu began, students in Texas watched with a vested interest. The Texas Education Agency made recommendations to reschedule or cancel area and state-level competitions in an effort to limit student travel and minimize contact. With events approaching, like prom, spring concerts, and even graduation ceremonies, students waited as local school districts made careful decisions. Some districts halted student travel and others canceled school classes for a period of weeks.

Lubbock Independent School District GIS teacher Penny Carpenter knew GIS tools would be used to monitor and inform the public of the flu's pandemic potential, and she saw a unique opportunity for her students. Philosophically, Carpenter motivates students with relevant real-world topics, and the reality of H1N1 flu had certainly captured her students' attention. They found maps of countries and states with confirmed flu cases but none of Texas counties. Because the outbreak originated in Mexico, students looked to the border towns for reported infections, and that is when geographic inquiry began: Where were the counties in Texas with confirmed H1N1 flu cases?

The Texas Department of Health's Web site posted a confirmed case count by county and provided daily updates. Students created a list of Texas counties in a spreadsheet and entered the data of confirmed cases. Next, students used the school's
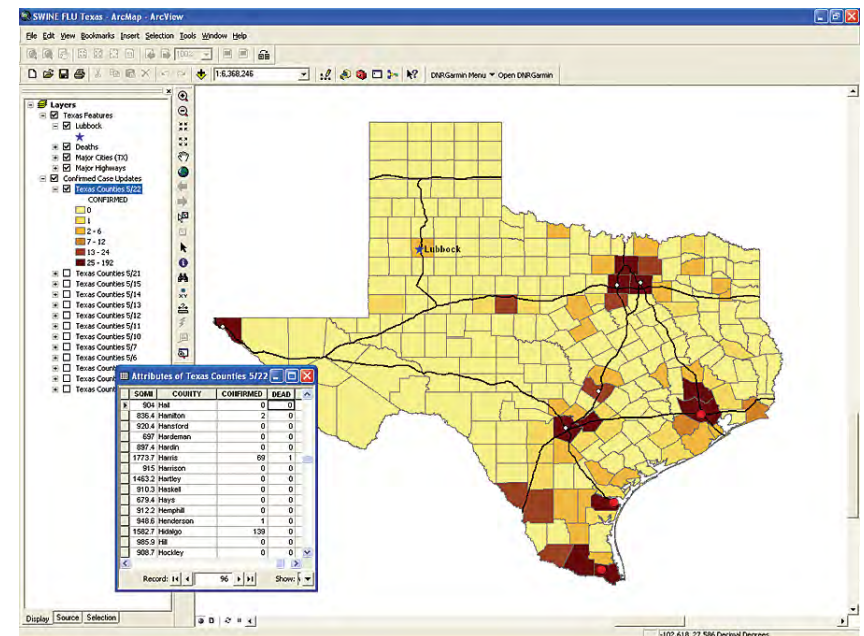
Students join flu data from a spreadsheet to the Texas counties attribute table to symbolize the case counts with graduated colors. In addition, data containing major highways, large cities, and locations of H1N1 flu deaths were layered.

ArcGIS Desktop ArcMap application to create a basemap of Texas counties. They joined the map's attribute table to the spreadsheet data by matching county names. After discussing appropriate breaks for the data range, the quantities of confirmed cases were mapped using graduated colors.

During the initial analysis, students discovered the darkest colors, representing the highest number of confirmed cases, appeared in the heavily populated areas, not the border counties. They discussed common aspects these areas shared that could explain the flu's spread. In the GIS, students added a layer of roadways and airports for comparison. Although each major area had a large airport, all areas were connected with major highways. This analysis supported the theory that travel by car was more likely to explain and continue the spread.

Students continued to update the data over the next several days and watched the flu spread along the roadways. Confirmed cases colored counties on the map moving west on Interstate 20, the major highway that connects Lubbock to the rest of the state via Highway 84. On the last day of school, the first confirmed case for Lubbock County was announced. The local television station broke the story and featured the work of Carpenter's students. Their GIS skills created a visual element that was relevant and meaningful to all of western Texas.

Student Tyler Funk explains, "I'm just in awe that I can build the maps in GIS to help other people understand the data and how

it affects them." Funk now contemplates areas of study that will develop his ability to construct datasets and analyze them

KCBD TV reporter Ann Wyatt films Tyler Funk as he uses ArcGIS Desktop to animate the spread of H1N1 flu in Texas counties.

through graphic representation. Carpenter believes she teaches more than building maps. "When students can visualize and see the data on a map, they begin to analyze, and this promotes higher-level thinking skills," she says.

About the Program

Penny Carpenter teaches Geographic Information Systems and Global Positioning Systems (GIS/GPS), an innovative course she proposed that was approved by the Texas Education Agency. It is one of many skill-based or career and technology education courses offered at her campus, the Byron Martin Advanced Technology Center (ATC). Courses are available at the ATC to all students from the four high schools within the Lubbock Independent School District. These weighted credit electives require no special application process, and many allow students to earn technical preparation or dual college credit. These courses promote career skills, and some provide opportunities for students to earn industry-recognized certifications. Career and technology education courses like GIS/GPS provide students with a pathway to the workforce and/or higher education.

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Visualizing the Results of High-Impact Student Field Experiences

By Matthew North, Associate Professor of Information Technology Leadership, Washington & Jefferson College

Since the 2007 publication of an Indiana University study on the value of engaged student learning, institutions of higher education throughout the world have increased their focus on what are now referred to as high-impact learning experiences. Dr. George Kuh, the study's principal author, defines high-impact learning as instructional practices that measurably increase student retention and engagement. Such experiences can range from internships or mentoring interactions to hands-on laboratory or fieldwork. Kuh offers 10 specific types of high-impact learning available to educators. These include collaborative projects, undergraduate research, common intellectual experiences, and community-based learning. Regardless of their exact structure, the evidence is clear that high-impact opportunities enhance both early comprehension and durable knowledge in students. Kuh says:

"The results clearly show that colleges and universities should do everything possible to encourage undergraduates to participate in at least two high-impact activities, one in the first year and one later in their studies. Such experiences will better prepare students for a productive, satisfying lifetime of continuous learning."

With the emphasis now placed on high-impact practices, professors face a sometimes daunting task of developing and offering engaging, impactful learning experiences for their undergraduate students. GIS can serve as an excellent tool to enhance such lessons and complement high-impact experiences in a variety of fields and disciplines.

A recent summer research project offered an opportunity to couple high-impact learning practices with ArcGIS through an Esri educational teaching and research lab kit. One professor and two undergraduate students at Washington & Jefferson (W&J) College, a small, private, four-year school just south of Pittsburgh, Pennsylvania, were afforded the chance to travel to the country of Costa Rica, where they participated in a water quality and contamination research study. Together with their faculty mentor, the students traveled to various regions of Costa Rica to sample river water downstream from population centers and industrial activity. Water samples were collected at numerous river sites and tested for mercury and other contaminant metals, as well as petrochemicals, that could be washed into river systems as a result of urban residential, manufacturing, or commercial agricultural activity.

Number of Turtle Species
☐ 1
☐ 2
■ 3
■ 4

Heavy Metals
— > 60 ppm
— 40 - 59 ppm
— 15 - 39 ppm
— < 15 ppm

Population Density
■ 6
■ 5
■ 4
■ 3
■ 2
■ 1

Using ArcGIS for Desktop in the lab, authentic Costa Rica field data was joined with existing GIS layers. Rio Parismina and Rio Jimenez (labeled) do not flow from heavily populated areas yet show elevated levels of heavy metals. These rivers flow toward a nesting area for multiple sea turtle species.

This project alone was a high-impact experience for the two students who were fortunate enough to participate in the field; however, once back on campus, the data collected and the field experience design have resulted in opportunities for numerous additional students, as well. ArcGIS has played a central role in enriching learning for students. Through the use of joins and relates in the software, students have been able to integrate the field data collected in Costa Rica into existing GIS data in a lab setting to explore spatial relationships. For example, they can investigate the relationship between the prevalence of various river contaminants and their proximity and impact to such areas as sea turtle nesting grounds. In turn, students are able to use GIS to model and analyze upstream zoning, environmental mitigation, and compliance enforcement efforts as they relate to contaminated rivers. This hands-on approach, using authentic data, has markedly improved students' comprehension and retention of spatial skills and competencies.

Water Quality Closer to Home

Further, the use of authentic field experiences and ArcGIS analysis has been successfully replicated in less expensive and less travel-intensive ways closer to home. Southwestern Pennsylvania, where W&J College is situated, is the current heart of Marcellus shale natural gas exploration and development. Hydraulic fracturing, or "fracking," as it has come to be known, is a primary process used in the extraction of shale gas—a process that yields thousands of gallons of contaminated water each day at sites throughout the Marcellus formation region. Much of this water finds its way into natural waterways in the college's immediate vicinity. Students are now able to learn about, research, analyze, and report on issues in the area they call home, adding a sense of personalization and urgency to their college experience. Some of these students come from families that earn their livelihood in the natural gas

industry, so an inherent opposition to gas drilling is not prevalent, especially prior to lab exercises. As students have collected and analyzed water quality data, an appreciation for the impacts of fossil fuel exploitation has been observed, opening the door for meaningful and informed conversations about meeting the world's energy demands while caring for an increasingly taxed planet.

Through high-impact learning experiences such as these, a generation of college graduates armed with an understanding of competing forces and the ability to use tools such as ArcGIS to make informed decisions is what is needed to strike the delicate balance required for future energy and environmental stability.

Dr. Matthew North is an associate professor of information technology leadership and an affiliated faculty member with the Environmental Studies Program at Washington & Jefferson College in Washington, Pennsylvania. He has published works on GPS and GIS technologies and is the author of Life Lessons & Leadership, Agami Press, 2011.

The author offers sincere thanks to Dr. Robert Hijmans of the University of California, Davis, for the use of GIS data from the DIVA-GIS project.

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Enriching STEM in Informal Education with GIS

Geospatial Summer Camp

Role of Technologies Expanded from Research to Teaching

By Kerry Lagueux, Heather Deschenes, and Maria Elena Derrien

The Harbor Discoveries Summer Camp is an environmental science day camp with a marine science focus. Harbor Discoveries is the first camp program to make extensive use of the Boston Harbor Islands National Recreation Area as a living laboratory for aquatic science education and environmental stewardship. Through a combination of hands-on science and traditional camp activities, the program seeks to foster an appreciation of the importance of habitats for all life and helps prepare campers to become future advocates for the planet.

Campers search for crabs located in the survey plot.

The academic component of Harbor Discoveries sets this summer program apart from many others. Each week's curriculum focuses on a particular theme. Using inquiry-based methods, the camp examines the interdependence of living things and compares similarities and differences among local habitats. By emphasizing scientific process skills, the program imparts informal science learning almost without students realizing it. Through hands-on, field-based experiences, participants are exposed to a variety of environmental issues pertaining to the marine environment.

GIS and GPS technologies are integrated into the camp week called Sea Lab, which is focused on budding marine scientists in the eighth and ninth grades. The Sea Lab week uses current research practices to explore marine biology, ecology, and now geography. This week was chosen because it focuses on hypothesis-driven research, which allows spatial thinking and concepts to be easily integrated with these activities. To keep the GIS and GPS component a hands-on one for all campers, class size was limited to 12 students and counselors ensured that each camper had the opportunity to interact with the GIS system and a GPS unit.

During this rigorous week, campers worked side by side with New England Aquarium researchers and camp counselors. They learned about scientific inquiry by developing hypotheses, performing fieldwork, and analyzing results. Before heading out into the field, they spent time in the classroom learning about the ecological components of the study, methodology, techniques, and technology. Classroom time also included fun team-building exercises. The aquarium is just a short boat ride away from the Boston Harbor Islands National Recreation Area, which provided an excellent field laboratory for the study of marine ecology. During the week, campers explored the six islands, took samples and measurements, and recorded and mapped the results.

Real-World Examples of GIS Use

The New England Aquarium has used GIS in its research analyzing the spatial patterns of North Atlantic right whales (Eubalaena glacialis) relative to fishing and shipping activities, which are two of the leading causes of mortality for this species. Because geospatial technology is an important and growing component of the New England Aquarium's research, camp program directors wanted to incorporate GIS and GPS technology into the analysis of the data collected by campers. Researchers and counselors teamed up with campers and provided examples of how the aquarium employs these technologies in its research.

A summer camper takes a dissolved oxygen measurement of the sample site.

In addition, having a GIS and GPS component in the curriculum gave campers the opportunity to acquire spatial-thinking skills. President George W. Bush's High Growth Job Training Initiative has defined geospatial technologies as one of the leading job growth areas, and spatial thinking has been identified by the U.S. National Research Council as critical to success in the workplace and science.

After a short introductory lecture on GIS and GPS technology, campers worked a small tutorial that taught them the essential elements of a map and how to add data and symbolize layers. Before heading out into the field, campers also tested GPS units. They could explore the units of latitude and longitude, as well as positional accuracy, and how this relates to potential problems with buildings that block the direct line of sight to the

sky. Counselors gathered the coordinates students collected and displayed these locations using the GO TO X,Y tool in ArcGIS 9.2. These coordinates were displayed on a map with high-resolution photographs.

Enhancing Crab Study with GIS

This year's study focused on crab ecology. specifically crab population dynamics relating to water quality and substrate. Campers, organized into small groups, collected data on dominant crab species, diversity of crab species, percentage of females, and percentage of pregnant females. Along with the crab information, the campers collected information on water temperature, pH, salinity, dissolved oxygen, and substrate type. Secondary topics covered were water pollution, invasive species, and potential correlation between environmental variables and crab biology.

As they explored the biological and physical diversity of this area, campers visited seven Boston Harbor Islands. When the campers arrived at the sampling site, they laid down a quadrat (a sample area, in this case, a square- meter rectangle) within the intertidal zone. Intertidal height varied at each site depending on the tidal stage, but the study mainly focused on midintertidal regions.

At each site, the campers used the GPS units to determine the latitude and longitude position and recorded this information on a data sheet. Next, campers took measurements of various water quality parameters using appropriate instruments (e.g., pH meters, salinity meters). In the last step, all the crabs in the quadrat were collected and placed in a bucket to be sorted by species, then sized and sexed. Finally, it was determined which females were pregnant.

At the end of each day, campers transferred data from field data sheets to a spreadsheet that replicated the data sheet but also automatically converted the degrees, minutes, and seconds obtained from the GPS units to decimal degrees for easy integration with ArcGIS.

Campers also spent a night on one of the islands. This trip featured many fun activities and required that campers make at least five maps. Each group received detailed instructions that included how to bring the Microsoft Excel spreadsheet into the GIS program; change the symbolization; and add a title, north arrow, and scale bar to their final maps.

A map of the substrate type at each sample site was created by the summer campers for the poster displays.

Each group of campers decided which crab variables and water quality parameters it would map to make sure all the field measurements were represented on maps. This data was overlaid on a basemap of data layers downloaded from MassGIS (www. mass.gov/mgis/) to provide the spatial context for the mapped parameters. Each map was created from a template, but each group could choose colors and symbolization as well as a title for the map. The counselors provided guidance on symbols and titles that helped make the maps more easily understood.

As campers finished their maps during the evening, counselors and campers discussed the findings from the week and how to display the results on the maps, emphasizing potential geographic and biophysical factors. Campers had access to tables of historic water quality data so they could compare their results to measurements over the past decade.

On the final day, campers arrived back at the aquarium, bleary eyed but eager to finish the project. Office supplies were on hand to help campers assemble posters that explained their methods and findings and displayed the spatial patterns of their results.

Conclusion

Geospatial technology was easily integrated into the Harbor Discoveries Summer Camp and became a perfect complement to the field component of the Sea Lab week. The use of GIS and GPS technology will be incorporated into other weeks of the summer camp to allow for broader spatial education. Campers who participate in plankton tows will record their locations and map the plankton distributions. Other campers who will be sailing for a week will map their locations, record interesting observations along the way, and prepare souvenir maps of their travels to take home.

The integration of these technologies increases not only the spatial awareness of the students relative to their travels during summer camp but also to the spatial relationships in the marine

world. Next year, the camp directors will work on ensuring all study variables have logical ecological connections.

Acknowledgments

Kerry Lagueux is an associate scientist at the New England Aquarium where his research focuses on analyzing patterns of marine animals relative to oceanographic variables and anthropogenic impacts. He holds a master's degree in geography from Western Washington University and a bachelor's degree in geography from San Diego State University. His professional interests include spatial modeling, satellite tagging, marine GIS, geographic visualizations, and education relating to geospatial technologies.

Heather Deschenes is the supervisor of the Harbor Discoveries camp and has worked at the aquarium for more than 10 years. She has helped forge many partnerships between the program and scientists willing to share their expertise with the camp participants.

Maria Elena Derrien graduated with dual bachelor's degrees in biology and marine science from East Stroudsburg University and received a master's degree in marine ecology from the University of Massachusetts, Dartmouth. During more than 10 years working in the field of science education, she has taught environmental education and created curriculum for the New England Aquarium's Harbor Discoveries program. She is currently an elementary science teacher for kindergarten, first, and fourth grades at Buckingham Browne and Nichols School in Cambridge, Massachusetts.

(This article originally appeared in the January–March 2008 issue of *ArcUser*.)

4-H Club GIS Programs Support Science and Technology Training

Members Prepare for Future Education and Employment

By Jim Baumann, Esri

Across the United States, 4-H clubs have implemented GIS programs—supported by grants from Esri—that have enhanced members' understanding of science and technology and enriched their communities.

Jim Kahler, 4-H program specialist, United States Department of Agriculture (USDA), comments, "GIS technology contributes to the 4-H science program goals because it teaches youth about a technology that most have never used. They also learn more about the subject that they are mapping—plants and animals, wildlife, natural resources, or historic places. GIS is also a good tool to integrate with other 4-H content areas, such as nutrition and health, citizenship, and communications."

A. B. Graham, a school principal in Springfield, Ohio, is credited with starting what was to become the 4-H Club. In 1902, motivated by the large numbers of young people who were leaving their farms for work in the city, Graham began promoting after-school programs to educate youth in the practical arts of scientific agriculture to improve crop harvests and safely preserve food. The national 4-H organization was officially formed in 1914 when the United States Congress created the Cooperative Extension Service within USDA, consolidating
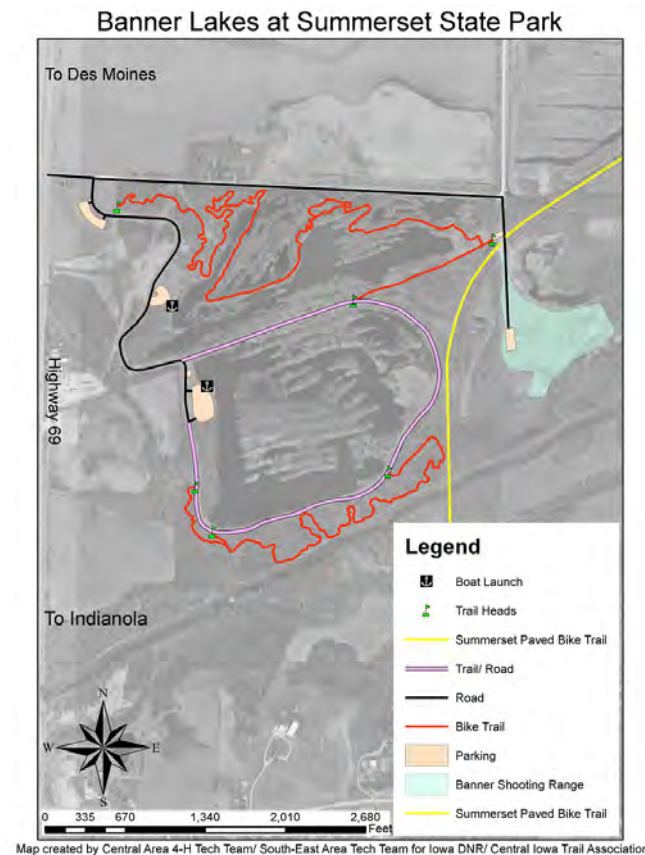
A joint project between two 4-H Club Tech Teams in Iowa to map the trails and facilities available in local recreational areas.

various boys' and girls' clubs that were involved with agriculture, home economics, and related subjects.

Later, the 4-H after-school curriculum was expanded to include technical programs, such as the 4-H Science Initiative, which supports the STEM program implemented by the US government to improve the science and technical skills of elementary and secondary school students.

The goals of the 4-H Science Initiative and STEM program are being promoted through projects such as the USDA's Economic Research Services Food Environment Atlas. For this project, 4-H clubs have collected data regarding the availability of wholesome food within their communities. Other projects have included work with local US Fish and Wildlife professionals, mapping wildlife refuges and identifying areas of concern for future monitoring. Clubs have also mapped invasive weed infestations and assisted with local disaster preparedness plans. These projects allow club members to not only improve their STEM skills but also meet 4-H requirements for community service projects.

Since its inception in 2004, the 4-H GIS Software Grant Program, sponsored by Esri, has helped more than 725 4-H clubs begin and sustain GIS programs for their members with grants of ArcGIS software and Virtual Campus training.

Esther Worker, informal education manager at Esri, says, "The GIS software grants have empowered 4-H youth to take an active role in researching and investigating their communities. 4-H youth are
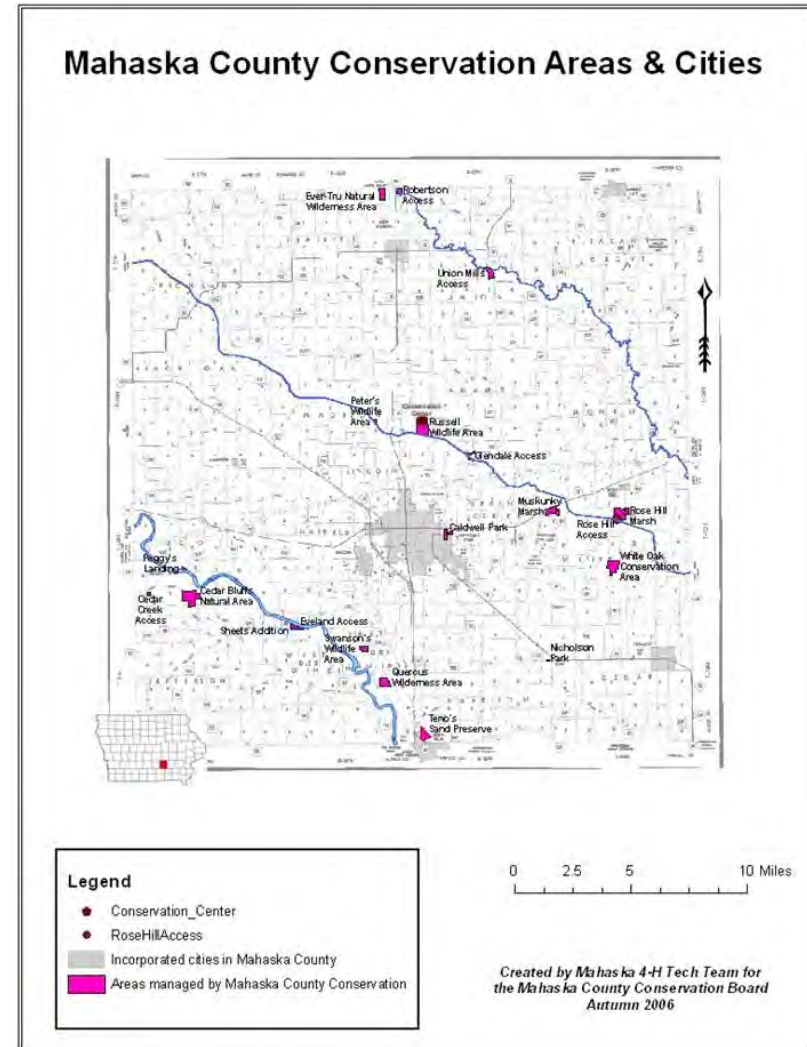
A map depicting all the conservation areas and cities in Mahaska County, Iowa. It was the first map created by the 4-H Southeast Area Tech Team.

learning about community, technology, and careers as a result of their GIS service projects.

"Another benefit derived from the relationship between Esri and 4-H is the opportunity for the 4-H national GIS/GPS leadership team to send delegates to Esri's annual Education User Conference [EdUC]. The team comprises selected 4-H youth and their adult mentors from across the United States. At the EdUC, they participate in local mapping projects, attend sessions and workshops, and present projects they have been working on during the preceding year."

Debbie Stevens, adjunct professor at William Penn University, has been a volunteer with her local 4-H Club in Oskaloosa, Iowa, for more than six years. The area has a long history with 4-H, and many current members have great-grandparents who were once in the same local club. Because 4-H is a traditional part of community life, Stevens has been successful in raising money from local businesses for funding special projects, such as buying the equipment needed for their mobile tech lab.

"Our community leaders didn't know much about GIS at the time," says Stevens, "but because we were focusing on the benefits to youth and using emerging technology, prominent businessmen supported the project and had faith that our 4-H youth would benefit, as would our community. We were able to purchase 10 laptops, a wireless printer, digital camera, GPS kit (with 10 Garmin eTrex units and 10 compasses), and 2 Recons."

Since her involvement with the club, the local 4-H Southeast Area Tech Team has completed a number of GIS-based community projects that include plotting the location of available industrial properties for economic redevelopment; creating trail and facility maps in local recreational areas; and mapping cultural, retail, and commercial downtown districts for the Oskaloosa Chamber of Commerce.
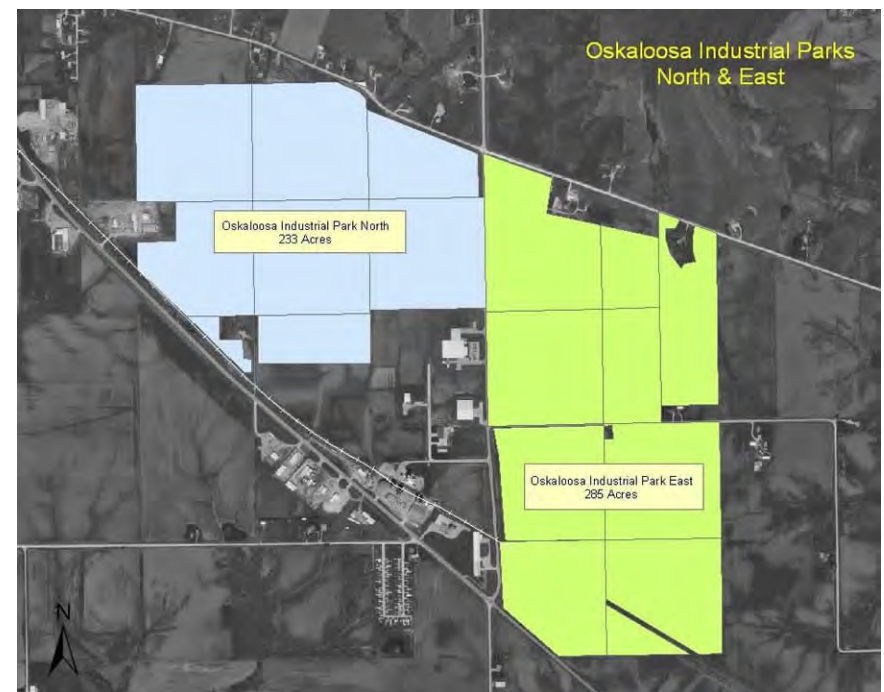
A map of available industrial properties in Oskaloosa, Iowa, created for the local economic development group for strategic planning purposes.

The group is currently preparing a major project with officials in Oskaloosa that involves a citywide inventory of all ash trees. The data collected will be used to institute an abatement program in the event of an emerald ash borer infestation. This highly destructive insect was first detected in the United States about 10 years ago and has spread rapidly since that time. The data collected by the 4-H group will also be made available to the USDA Animal and Plant Health Inspection Service, which is coordinating a national effort to minimize the ecological impact of this invasive insect.

The club also maps the locations of local hog confinements, referred to as confined animal feeding operations. Mapping these sites provides critical health and planning information for the community, as hogs living in confined areas produce excessive amounts of excrement that decomposes into a variety of particulate matter and toxic gases, including ammonia and hydrogen sulfide. When these gases are released into the atmosphere, they can be detrimental to the health of those in the area.

Stevens concludes, "This is the information age, and it is critically important for youth to learn IT skills. I can think of no better information management system than GIS—all pertinent information is stored in tables directly related to locations on a map. The map is used to paint a picture with that data. Whether it is about climate or transportation, a map is much easier to read and understand than analyzing the related spreadsheet.

"So when you can connect young people to an activity that is relevant in nearly any career path—transportation, government, business, science, conservation, environment, education, agriculture, emergency planning, forestry, fire fighting, community planning, health care—and the application is fun, you can't lose!"

(This article originally appeared in the Winter 2011/2012 issue of *ArcNews* Online.)

Intensive Summer Course for High School Students

Skills Flow from Water Study Program

By Nicole Minni, University of Delaware

A summer program for Delaware high school students used GIS and GPS technologies to reinforce math and science skills while studying how water flows in and around the Georgetown campus of Delaware Technical & Community College (DTCC). This U.S. Department of Education funded TRIO program met one day per week for six weeks during the summer of 2007.

Four presentations kicked off the first day of the summer program. "Using GIS to Study Human Impact," "Understanding Watersheds," "Using GIS as a Tool for the Research Question," and "GPS/Geocache Instruction" introduced various aspects of the research that the student would undertake. Students also learned how to use GPS units by participating in a scavenger hunt on campus that also introduced them to geospatial-related career choices. After locating each station using coordinates, students listened to presentations by professionals in a variety of fields including nursing/paramedics, soil and water conservation, communications, biotechnology, educational technology, and architectural engineering.

The second day began with a presentation on how surface porosity affects a watershed's health. Students discussed surface types they had seen on campus with their leader and teacher.

They looked at examples of the techniques Villanova University is using to control flow rate and filter runoff. Using ArcGIS, students learned how to heads-up digitize pervious and impervious surfaces using a high-resolution, infrared digital orthophotograph

Students diligently placed storm drain medallions on the DTCC campus, creating awareness that the storm water leads to Deep Creek and that what we do on land affects water quality.

as a basemap. They digitized data on sidewalks, parking lots, storm water ponds, building footprints, and grass areas.
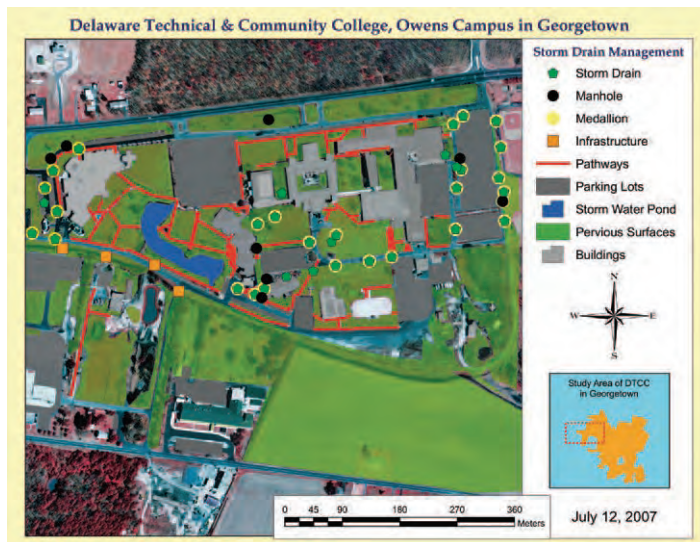
One of the high-quality and detailed maps that students created for this project

After reviewing the watershed connection—how what is done on land affects water quality—at the beginning of the third day, students used GIS to look at where they were on campus in relation to water bodies. They discovered that water from the campus flows from Deep Creek into the Nanticoke River, which empties into the Chesapeake Bay.

The students began feeling they were a part of something bigger. A guest speaker from DTCC's grounds maintenance staff told

how a storm in 2006 destroyed two bridges on campus. The staff reexamined how the storm drainage system worked and made improvements to it. Using a map and GPS units, the students collected location data for storm drains, infiltration trenches, and manholes.

The group was divided into indoor and outdoor teams on the fourth day. The indoor team continued working on the data needed to finalize their research and maps, while the outdoor team placed storm drain medallions around the campus that read "No Dumping, Drains to Creek." Students chose medallions

Through their use of GPS and GIS, students were able to learn the importance of drainage systems, identify drainage problems on campus, and find solutions for these problems.

with a frog graphic because frogs can tell quite a bit about water quality.

On day five, the students journeyed to Trap Pond State Park. Located in the Nanticoke Watershed, it is also known as Delaware's Cypress Swamp. Students learned some of the history and benefits of bald cypress trees and how non-point-source pollution runoff resulted in a ban on swimming at the park. Next they took a tour of Perdue's AgriRecycle Center, where they learned that farmers are helping clean up Delaware's waterways by having chicken litter removed from their farms, recycled, and shipped to other places to use as fertilizer.

On the sixth and final day, the students recapped what they had learned. Through their use of GPS and GIS, students were able to learn the importance of drainage systems, identify drainage problems on campus, and find solutions for these problems while creating awareness in the community. They observed that poor drainage leads to pollution and land runoff which, in turn, affects the land or body of water into which it drains. With storm water, sediments and other pollutants damage the fish, wildlife, and plants.

The students' energy and excitement was evident. Some of their suggestions for improvements on the college campus included

- Replacing the raised bed by the entrance with a bioinfiltration traffic island

- Creating a native-plantings buffer around the southern end of the storm water pond

- Placing more trash receptacles around the campus

- Replacing blacktop with pervious pavement in staff parking areas

- Investigating the idea of green roofs on campus

They asserted that through maintaining and respecting the environment, students and others in the community can foster a better quality of life.

To learn more about the TRIO program, visit http://www.dtcc.edu/owens/ccp/SSS_Trio/Pages/TRIO1.htm. To learn more about GIS in Delaware, visit http://stateplanning.delaware.gov/dgdc/.

(This article originally appeared in the Summer 2009 issue of *GIS Educator* newsletter.)

Strengthening STEM Career Paths with GIS

Maine High School Geography Teacher Emphasizes Geospatial Thinking

By Jim Baumann, Esri

Longtime Bangor High School geography teacher Margaret Chernosky's epiphany came nearly 10 years ago in an advanced placement (AP) human geography training course.

"The instructor showed us some of the Atlanta [Georgia] demographic data in a desktop GIS, and I sat there completely enthralled. Completely. I realized that this is how you teach geography."

Chernosky knew that to successfully integrate GIS technology into her own classroom instruction, she would have to first master it herself. Initially, she took online classes. Later, she attended training seminars in Colorado, Costa Rica, and New Zealand. "Besides being fun," says Chernosky, "the travel brought me into contact with people around the world that were equally enthusiastic about GIS. I'm still in contact with many of the people I met at the seminars. It's a real community."

During this period, in addition to her full-time teaching responsibilities, Chernosky earned a masters of education degree in geospatial education. "My motivation was to not only learn as much about geospatial technology as I could but also to learn how to think geospatially. And this is what I try to bring to my students—this new way of looking at the landscape."

Bangor High School students created this poster and many more using geospatial analysis and ArcGIS.

Throughout this period, Chernosky had become familiar with ArcGIS software and Esri's training courses. When she introduced GIS to Bangor High School students in small steps, she assigned participation in Esri's Community Atlas project to her 2005 AP human geography class. Students and teachers throughout the United States annually contribute to the Community Atlas by

examining aspects of where they live, then posting descriptions and maps of their community related to their findings.

The following year, Chernosky proposed the addition of an elective class, GIS in geography, to the Bangor Area School District, which was subsequently approved. Today, because of strong student demand, two sections of the GIS in geography course are offered. While they are open to all students, Chernosky encourages sophomore participation so that those students can apply the GIS skills they have gained to their other high school courses, such as history and science. The maximum class size for the GIS course is 16 students. Because the classes have a limited number of students and the required projects that the students work on are completed in pairs, there is a great deal of interaction and cooperation among the students. Stacy Doore, a GK12 Sensor fellow, University of Maine, Spatial Engineering, has worked with Chernosky for several years to develop and teach the GIS in geography course.

The five steps of geographic inquiry provide the basis of instruction that Chernosky employs in her classroom to direct her students in the creation and completion of GIS projects. The steps include the following: ask geographic questions, acquire geographic resources, explore geographic data, analyze geographic information, and act on geographic knowledge. She introduces the concepts gradually to the class, discussing articles found in ArcNews and ArcUser so that students can gain a greater understanding of the geographic inquiry method.

Students complete two major projects during the year. The first is participation in National Geographic's annual Geography Action! program. Themes change each year and focus on either a location, such as Europe and Africa, or an aspect of physical or human geography, for example, conservation, cultures, and habitats. Chernosky tries to get her class to complete this project by mid-November in time for Geography Awareness Week. She has forged a relationship with the local newspaper, Bangor Daily News, and the editor publishes a full-page color spread highlighting the classroom work for five successive days.

Says Chernosky, "We have a relatively small, close-knit community here in Bangor, and the newspaper is truly committed to education. In addition, the editor and I have developed a reciprocal relationship. When needed, I help him with graphics that require maps. For example, on election night I plot the results in ArcGIS Desktop in time for him to meet the press deadline for the next morning's newspaper."

The students' year-end capstone projects focus on the analysis of local or regional issues that have a direct impact on the students themselves or their community. Chernosky initially holds a brainstorming session with the class, and they discuss local issues to develop the related geographic questions necessary to direct their projects.

"Basically, we look for projects that are of local interest, deal with local concerns, and have relevant data available," explains

Chernosky. "The majority of our data comes from the Maine Office of GIS. Its rich datasets are online and downloadable. From there, we get topographic maps, contours, rivers, roads—really high-quality, complete base files to work with. We acquire other required geospatial data from local agencies. Or if need be, we create our own data." The students have a variety of GIS software available to them, including ArcGIS, ArcGIS 3D Analyst, ArcGIS Spatial Analyst, ArcGIS Network Analyst, ArcGIS Publisher, and ArcLogistics.

The completed capstone projects are subsequently entered into the Maine State GIS Championships, where the students personally present their finished work to the judging panel. In the 2009 contest, a sampling of the projects included "The Answer, My Friend, Is Blowing in the Wind," "Optimizing School Bus Routes," "Air Quality Monitoring in Penobscot County, Maine," "Determining Wireless Signal Using Indoor GIS," "Access to Health Care in Rural Maine," and "Cancer and Poverty in Maine." In 2010, students examined the temporal and spatial patterns of crimes to motor vehicles in Bangor. After the contest, students presented their work to the Bangor Police Department.

Concludes Chernosky, "I'm not necessarily trying to convince my students to follow careers in GIS, though I believe there are many very exciting opportunities open to them. My goal is to get them to see things in a new way. I want them to really understand the spatial component of the steady stream of information bombarding their daily lives and how geospatial thinking can provide them with a greater understanding and awareness of the many things they will encounter.

(This article originally appeared in the Winter 2010/2011 issue of *ArcNews*.)

The Learning is Exponential: Using a Community-Based Approach

By Susan Harp, Esri

This article is the first in a series honoring individuals who have made a difference in the world by applying a GIS solution to challenges or needs within their communities. Since these unique individuals have been selected for their innovations or special achievements in a particular field, the series is appropriately named GIS Heroes. The first honoree, Mark G. Ericson, works in the field of education.

Over its 110-year history, the Santa Fe Indian School (SFIS) has evolved from a federally run school to becoming, in the 1970s, the nation's first Indian-run school for Native Americans. Today owned and operated by the 19 Pueblos of New Mexico, the middle school and high school accommodate both day and boarding students from tribes all over New Mexico. Appropriate for its Native American student population, the school offers coursework in Native American history but also strives to prepare students with technical skills they need in the modern world.

Not only are the students at SFIS learning computer skills and scientific research concepts in the process, but they are also learning how to communicate and work with professionals and elders in their tribal communities. This program, called

Community Based Education Model (CBEM), is an innovative approach that seeks to motivate and strengthen learning by involving students in real world issues that require math and science skills. CBEM also seeks, through community involvement, to motivate students to continue their educations and return to their communities to work.


When SFIS science instructor Mark G. Ericson helped design SFIS's first CBEM curriculum in 1996, he already had almost a decade of experience teaching at SFIS, so he had a good understanding of local education and community issues. He is also the catalyst for using GIS to bring his students and their communities together. For the past five years, under Ericson's instruction, SFIS students have been using GIS skills to participate in and contribute to environmental and water management programs in their communities.

"I was looking for something that could be used as a foundation to create an expandable base that students could add to based upon their work in the community," says Ericson. "The use of GIS has been the technological core." He and other CBEM curriculum developers worked with community members as equal partners to select relevant projects. Since many issues were based on the environment, Ericson investigated combining computers and geography as a way to use the 24-computer laboratory that Intel Corporation had provided for CBEM. Program funding came from the U.S. Department of Energy. Through contact with local agencies involved in land management, Ericson heard about ArcView software and started teaching himself how to use it for classroom instruction; later, he would go to Esri headquarters in Redlands for more training.

Ericson's course teaches students GIS software skills to use in community projects. Over the past seven years, CBEM students have used GIS to map back roads and tribal land boundaries. They have participated in wetlands restoration projects, ground and surface water monitoring, and longitudinal aquatic habitat assessments. They use U.S. Geological Survey data on their reservations and watersheds and digital elevation models to create a master map with the ArcGIS Spatial Analyst extension. Their master map provides a base for further learning such as using ArcView software's hydrologic modeling extension to derive stream channels and watershed basin flows. In the process, they
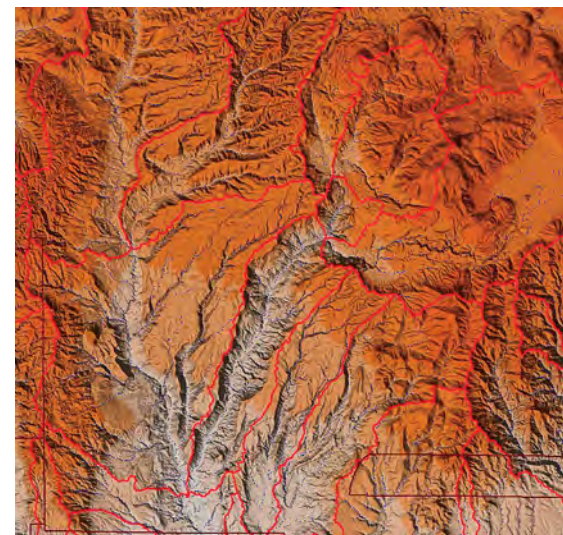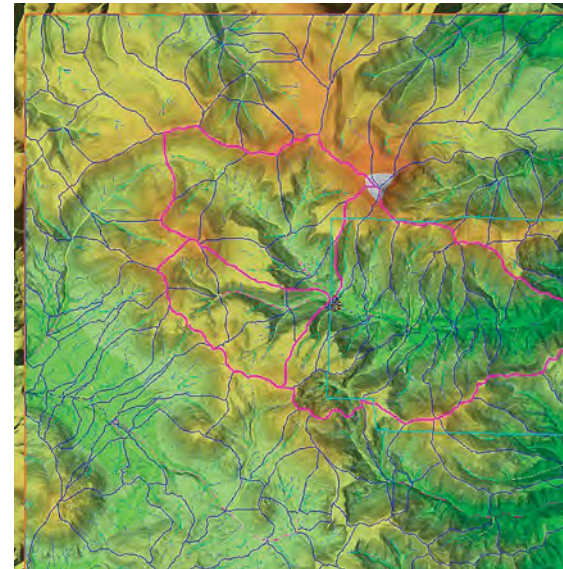
Top and bottom: CBEM students use GIS and hydrologic modeling to visualize the extent of the watersheds that feed their reservations.

have learned skills that help them continue their educations or find jobs.

"When students wade through a stream trying to get a clear GPS signal to map study area boundaries, the learning is substantial; when the data is then realized in a multidimensional mapping database, the learning is exponential," says Ericson.

He adds that students also discover new things about themselves, such as their ability to understand and apply technical concepts, communicate these ideas to others in a public setting, and contribute as citizens to their communities. As a result, more than half of the approximately 200 students who have participated in CBEM continue in further education and community work related to issues studied during their coursework.

"Mark's use of GIS has given the CBEM students the opportunity to learn in high school at the highest level in terms of computers and technology," says CBEM community liaison Matthew S. Pecos. "The communities get the direct benefit of the skills and knowledge these students have acquired."

"The kids are proud of what they can do, they are lifting their heads up high because they know they have a skill that many other people do not have, and they have progressed in other areas because of that," says Theresa Chavez, past CBEM coordinator and currently SFIS middle school coordinator. Many students have worked summer jobs doing community GIS projects such as mapping utility manholes and georeferencing house addresses.

As a measure of the school's success, in 1987 the United States Department of Education listed the school as one of 270 outstanding secondary schools in America. Of the 70 to 90 students graduating each year, about 90 percent of them plan to go on to attend postsecondary schools.

For more information on, or to suggest a candidate for, the GIS Heroes series, contact info@esri.com.

(This article originally appeared in the Fall 2006 issue of *GIS Educator* newsletter.)

# Spatial Statistics Provide New Insights: Researcher Sees Possible Links Between MS and Other Diseases

By Susan Harp, Esri

George de Mestral envisioned the design of the Velcro fastener in 1948 while picking burr-covered seedpods from his dog's fur after a mountain hike. As the story goes, the Swiss citizen stopped to observe the sticking qualities of Mother Nature's design and made the leap to a new, creative application. With the avalanche of information available to researchers today, the catalyst that helps produce this kind of "ah hah!" moment is extremely valuable.

For Megan M. Blewett, a young 21st-century researcher, spatial geography played a role in both her ah-hah! experience and her research. Blewett turned 18 in 2007, but five years ago, she was already reading a neuroscience textbook and asking questions about a mysterious disease—multiple sclerosis (MS)—that she found described in its pages. Blewett said, "I started researching MS when I was 12 and have since fallen in love with discovering the insights spatial statistics can give."

MS affects the central nervous system. Although its cause is unknown, many researchers think environmental triggers might be a factor. This unsolved puzzle caught Blewett's attention. She started collecting data about MS cases in her home state of New Jersey, learned to map their distribution with GIS, and has

been using spatial statistics tools to analyze that distribution. She has continued reading about the neurological and biochemical aspects of the disease. However, her ah hah! moment occurred at a science fair while she was talking with one of the judges about her map of MS distribution in New Jersey.
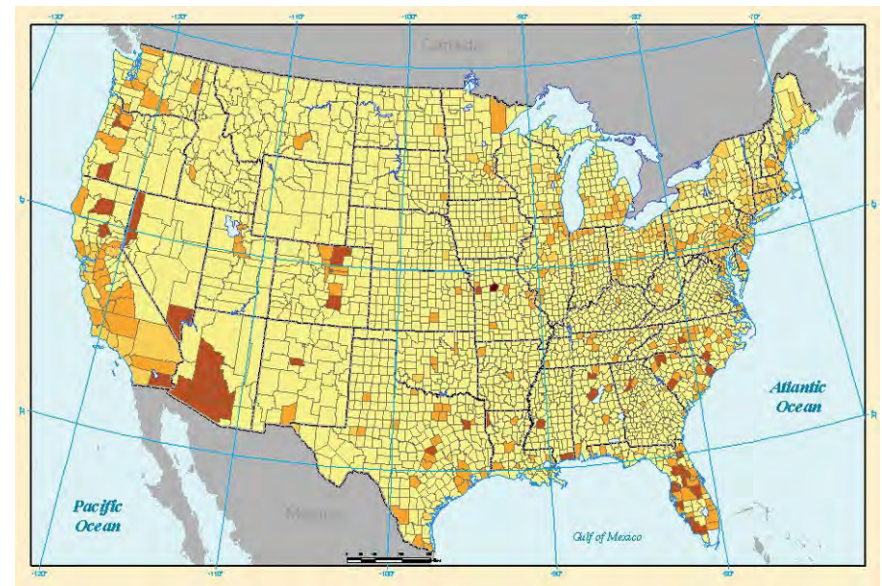
Normalized count of multiple sclerosis deaths by county for 1998 over 1990 census data

"I just got lucky there," commented Blewett. "I was looking at a state map of MS distribution and saw that my county, Morris County, has a high incidence of MS. You could see individual towns, and I knew the town next to me had a high incidence of Lyme disease." A bacterial infection, Lyme disease is spread by tick-borne spirochetes. She was already using ArcGIS Desktop to map MS distribution, so when she started thinking about a possible Lyme disease correlation, she added Lyme data to her map layers.

"I saw all these correlations and results that I hadn't been able to see before and still don't think I would have been able to see
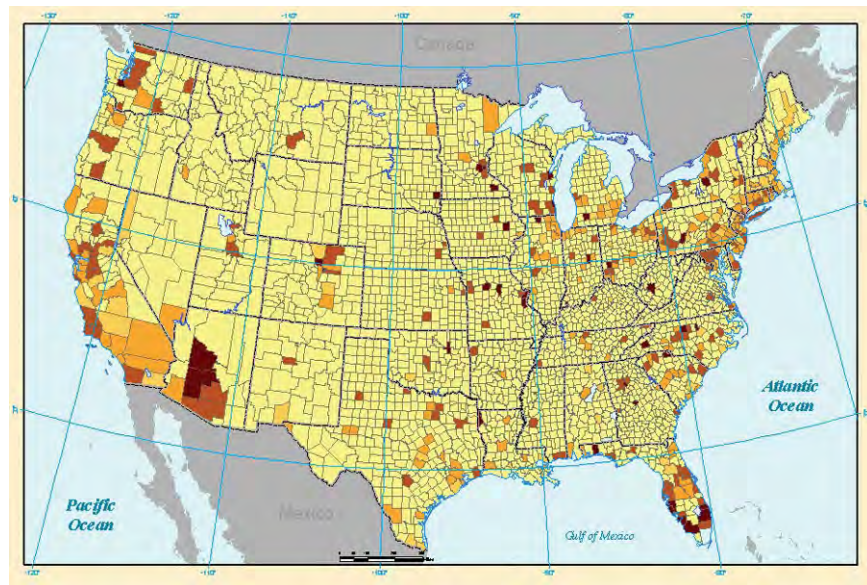
Normalized count of Lyme disease deaths by county for 1998 over 1990 census data

if I had been using more conventional chemical research to look at individual proteins at work," Blewett added. "Spatial statistics allowed me to see the bigger picture. Then I zoomed in to look at proteins at work in MS and related demyelinating diseases. I like to say my research path is analogous to reading the summary before reading the book."

The data collection process was one of the harder parts her research. Data came from TheDataWeb, an online set of libraries, and DataFerrett, a data mining tool, both provided free to the public by the United States Bureau of the Census and the Centers for Disease Control and Prevention (CDC). When Lyme disease data was not available online, Blewett had to contact the state epidemiologist and request data. Eventually she received data from every state. "To my knowledge, it is the largest standardized dataset of Lyme information in existence," said Blewett about the dataset. She also said she is willing to make the data available to other researchers.

Blewett ran a correlation analysis. She calculated a Pearson's correlation coefficient (r) (for the normally distributed variables) or Kendall's tau-b or Spearman's rho for data that was not normally distributed. All correlation analyses assumed a linear relationship between the variables so the appropriate coefficient was calculated for pairs of variables in three datasets. All variable values were converted to z-scores for use in a regression analysis. Finally, cartographic analyses compared MS, Lyme (from other

specified arthropod-borne diseases data), and control data from external cause of death data.

"The two disease distributions were pretty similar—they correlate and the control doesn't," explained Blewett. "Biochemically they are also very similar, so it has just taken off from there." She hypothesizes that both diseases may share a common spirochetal basis, and MS might develop from a secondary tick bite.

Blewett consulted with Esri spatial statistics expert Lauren Scott on using GIS in her research. "While biologists and medical researchers investigate this hypothesis at the cellular level,

Megan's work examines the spatial fingerprint of these two diseases at broad spatial scales and then tests hypotheses regarding their spatial correlation," said Scott.

"I wish to expand my research from a national to a global scale, while also testing my models in smaller geographic areas," Blewett said. "A recent study suggests that MS is, in fact, 50 percent more common than previously predicted."

Blewett presented her work at the 2006 Esri International User Conference and participated in the Academic Fair during the 2006 Esri Health GIS Conference. In 2007, she was accepted into several top universities and awarded seventh place in the prestigious 66th Annual Intel Science Talent Search.

(This article originally appeared in the October–December 2007 issue of *ArcUser*.)

Control data: normalized count of external causes of death by county for 1998 over 1990 census data

Collaborations and Partnerships

Unlocking the Educational Potential of Citizen Science

"Geo Learning"

A column by Daniel C. Edelson, Vice President for Education, National Geographic Society

I have been a fan of citizen science for many years, but I do not think the citizen science movement has had the educational impact that it could. Citizen science is the name for scientific research projects that engage members of the public in some aspect of their research. There have been some high-profile citizen science projects recently in which members of the public have conducted image analysis and solved protein-folding problems, but the overwhelming majority of citizen science projects involve crowdsourced data collection

For example, some of the largest and longest-running citizen science projects are in ornithology. In projects like the National Audubon Society's Christmas Bird Count and the British Trust for Ornithology's Garden Birdwatch, birders contribute their observations to databases that scientists use to track trends in bird populations and species distributions.

These two projects, like many others, fall into a category of citizen science project that I call community geography. In community geography projects, the data is georeferenced and used for spatial analysis.

Community geography projects can be a boon for researchers. Volunteer data collectors provide investigators with the opportunity to obtain a quantity and geographic range of data that would not be practical through any other mechanism. They are also a boon to participants, who get to join a community; participate in something meaningful; and, in many cases, learn some new science.

For as long as I've known about them, I've been fascinated by the educational possibilities of community geography projects. I'm a big believer in both inquiry-based learning and breaking down the boundaries between school and the real world. Community geography does both—except for one thing. Collecting data is only one part of the scientific process, and most community geography projects only engage participants in data collection.

In the stereotypical community geography project, participants take measurements or record observations and submit them to a central database for scientists to analyze. In some cases, participants are able to see a map of the data that has been submitted or see results of previous analyses that have been

conducted by scientists. However, it is very rare that participants have a chance to create and interpret visualizations or analyze data themselves.
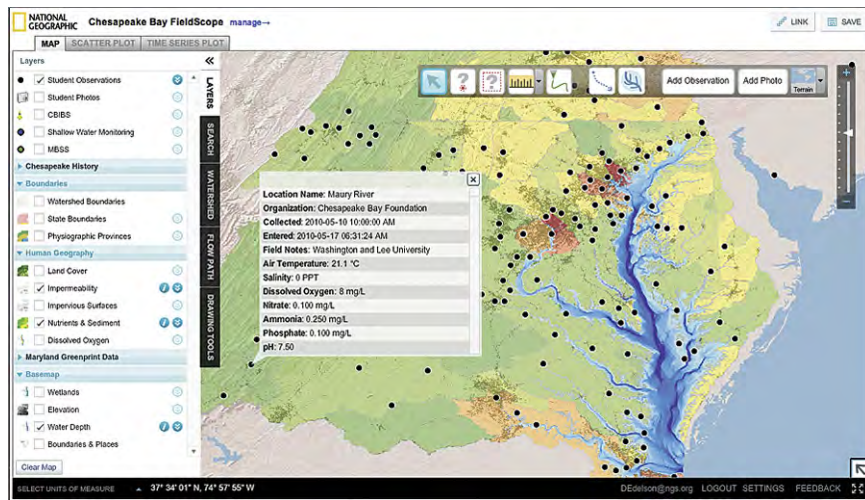
A FieldScope map from the Chesapeake Water Quality Project showing a student's water quality measurement.

After talking to organizers of community geography projects, I've learned that most of them would prefer to provide their participants with opportunities to work with the data, but they lack the resources or expertise to create tools that would enable their participants to do their own visualization or analysis.

So, a few years ago, National Geographic—with support from Esri and others—set out to create a web-based platform for community geography that would provide participants with the

ability to visualize and analyze their own data using GIS. We call this platform FieldScope. The idea behind FieldScope is that it is designed specifically to support citizen scientists—individuals who are interested and invested in researching a specific scientific question but who lack the training or technical skills of a scientist. This has required that we create easy-to-use interfaces and offer users a set of analytic tools that are either familiar or easy for a novice to grasp.

One of the first FieldScope projects that we deployed is dedicated to studying water quality in the tributaries to the Chesapeake Bay. Working together with environmental educators throughout the Chesapeake Bay watershed, we identified a set of water quality measurements that could be done by students and teachers across a wide range of grades, and we created a FieldScope application that displays not just student-collected water quality data but also a wide variety of data layers describing the land in the watershed, including land use, impermeability, and nitrogen yield.

We also provided users with analysis tools that enable them to create time plots and scatterplots for the data that they have collected, and we implemented a set of hydrologic analysis tools that will help them understand the underlying dynamics of the watershed. For example, we have provided users with a flow path tool that allows them to click anywhere in the watershed and see the path that water will flow from that point to the bay. Users

might employ this tool to see the portion of the river system that would be affected by a point source of pollution.

This Chesapeake water quality project has proved very popular in public schools; in the two years that it has been active, more than 600 teachers have received training on the software, and we have recorded more than 40,000 visits to the site. It is also succeeding in engaging users in analysis. In the first three quarters of 2011, we recorded more than 75,000 geoprocessing events and more than 45,000 uses of the query tools.

In the 2011–12 school year, both Fairfax County, Virginia, and Anne Arundel County, Maryland, have incorporated the project into their science curricula for all middle school students.

With support from the National Science Foundation, we are currently in the process of expanding FieldScope's functionality and creating authoring tools that will enable the broadest possible community of citizen science projects to build FieldScope applications for their own users. This spring, we will be launching FieldScope applications for two national community geography projects: Project BudBurst, which is studying plant phenology, and Frogwatch, USA, which is studying the distribution of amphibian species.

FieldScope, with its carefully designed user interface and specially selected GIS tools, is beginning to unlock the potential of citizen science as a learning experience. Teachers and students have responded enthusiastically to the opportunity to participate in geospatial analysis of data. In part, their enthusiasm stems from the fact that it's data about their own community that they helped collect. Administrators, in turn, are seeing that the entire experience of community geography is enabling them to achieve important learning outcomes for both science understanding and science skills.

Our goal over the next few years is to bring this powerful educational experience to as broad an audience as possible, young and old, in school and out.

For more information about National Geographic FieldScope and the Community Geography Initiative, visit natgeoed.org/fieldscope.

Read other articles in the GeoLearning series.

(This article originally appeared in the Spring 2012 issue of *ArcNews*.)

Students and Farmers Become Citizen Scientists

GIS Helps Community Investigate Local Lizard

By Karen Dvornich, University of Washington and Dan Hannafious, Hood Canal Salmon Enhancement Group

Editor's note: Attendees at the 2005 Esri International User Conference Plenary Session witnessed a live ArcView demonstration by three fifth-grade students. The demonstration was an example of how GIS technology was infused into school curriculum and field activities. These students represented 126 others who participated in a citizen science research project called Adopt-a-Farmer.

Waterville Elementary School students observed short-horned lizards (Phrynosoma douglassii) in farm fields in areas that conflicted with the modeled range distribution maps.

It all started in 1993 when Diane Petersen and Cathi Nelson, fourth- and fifth-grade teachers at Waterville Elementary School in the state of Washington, were investigating ways to engage their students in meaningful science inquiry. Traditional curriculum messages of saving tropical rainforests and endangered species had little appeal to youngsters most familiar with the farm fields in the high plateau of eastern Washington.

Petersen and Nelson discovered the NatureMapping program, which was designed to develop citizen scientists (both students and community members) by nurturing the local knowledge of place through science projects created in collaboration with the needs of regional biologists. The NatureMapping program provides initial teacher training and guidance to implement a comprehensive curriculum based on scientific inquiry. The program then helps develop local projects in part to verify range distribution maps modeled for every terrestrial vertebrate in the state.

The Development of a Long-Term Project

Early in the project development with Waterville Elementary School, students discovered that local observations of short-

horned lizards (Phrynosoma douglassii) in farm fields were in conflict with the modeled range distribution maps. The statewide maps, created by the Washington Gap Analysis Project, were modeled from 96 historical observations presented in the 1997 report, Amphibians and Reptiles of Washington State: Location Data and Predicted Distributions. Though students and community members have lived with the lizards (also known as horny toads) in the farm fields, the modeled range distribution maps showed that the lizards weren't supposed to be there.

Scientists, teachers, and students reviewed horny toad literature and local knowledge, developed a list of questions, and designed a spreadsheet with 22 attributes. Students first collated data on paper, then in the spreadsheet. Each year, the new students would use data from previous years to build their knowledge about scientific methodology, database management, and GIS. The new class of students would contribute additional data to the project and each year expanded the scope of the project to answer their own questions.

Parents and Local Community

In 1999, the Adopt-a-Farmer project began. This project is a creative way to obtain more data by asking farmers to report observations when they are out in their fields. The fourth-grade students wrote letters to the farmers they wanted to adopt.

Horny toad sighting observations were marked on the maps and labeled with numbered dots.

The NatureMapping program scientists supported the project by providing habitat descriptions and classification codes and worked with the students to design a data collection form. Students sent the form with instructions to their adopted farmers.

Farmers were asked to visit the school in the fall and bring their data from the fields. In preparation for their first visit, the class created a slide presentation that introduced the project and GIS.

Inviting the farmers, parents, and members of the local conservation district to help the students in a research project opened the door for questions such as What is GIS? What is Esri, and is that different from ArcView? What good is GIS in the classroom? How is this project going to help my child in school? Are horny toads an endangered species? The audience initially felt that GIS was a technology reserved for trained professionals and had difficulty imagining the technology being used by elementary school students. The audience was won over not only by the teachers' perseverance but also by the work students posted on their Web site and their explanation of what they did and why they needed more data.

Visiting the Classroom

The farmers were not only familiar with topographic maps, but they were also very good at training students how to use them. Horny toad sighting observations were marked on the maps and labeled with numbered dots. The other attributes from the data collection forms were reported on large poster paper at different stations within the classroom. After the farmers' visit, students used the labeled maps as the basis for on-screen digitizing of these locations using digital topographic maps in ArcView.

Accompanying data was entered into the project spreadsheet at the same time.

By the fourth year, Waterville students and their adopted farmers had collected more than 300 data observations. The expanding database was linked to the digitized points and overlaid on digital orthophotos and other statewide data coverage of rivers and roads. This allowed students to query the data and enforced database structure. It also helped these students develop a deeper sense of science inquiry.

The cooperative development of a science plan that would work in the classroom and in the field with the farmers was critical for the long-term success of this ongoing school project. In addition, the observations provided by the participating farmers as well as the students helped these students become state experts on short-horned lizards.

For students, it was important that GIS was used to answer their questions using their data. For teachers, it was about the genuine enthusiasm created by engaging the students in their local interests.

GIS Mentorship

There were two roles for the GIS mentor. The first involved database management. Computers set up in the classroom and the school district computer network did not come with standard protocols for file storage and access. It was essential that the

Waterville School District had outside technical support for GIS to help manage the data structure and nomenclature. Installing ArcView on a variety of classroom computers was efficient for teaching purposes as long as there was someone to help teachers

Some students were taught Microsoft Excel and ArcView 3.2 by the GIS mentor, then trained their peers. Other students wrote text; created graphics; took and posted pictures for the Web site; and, as shown here, created graphs.

maintain data integrity. The GIS mentor, whose phone number was written on the edge of the computer screen, could be called at any time when students were working with ArcView.

Students tended to select their type of involvement in the project based on expertise and interest. Many students had an aptitude for technology and were not afraid to learn and use ArcView. Typically, two to four students each year were taught Microsoft Excel and ArcView 3.2 by the GIS mentor. In turn, they trained their peers. Students not directly involved with ArcView assisted by writing text, making graphs, creating graphics, and taking and posting pictures for the Web site. However, all students learned to create map layouts of their farmers' lands and the associated horny toad observations.

Support from School Administrators

Initially, support from the community, school administration, scientists, and GIS mentors made it possible for the teachers to build their confidence and knowledge about scientific methodology, database management, and GIS. Students' questions prompted additional research, which resulted in the overwintering project, food preference study, behavioral studies, and the radio tracking project. Teachers also learned how to use other GIS tools for performing queries, making distance measurements, converting individual farmers' fields into separate shapefiles, and creating layouts. The database, which began with

96 historic records collected by scientists, now has more than 600 new records from farmers and students.

The NatureMapping program's teacher training focuses on understanding the scientific, mathematic, geographic, and technical content necessary to teach what students need to learn to work on their projects as well as helping teachers understand how to connect what is taught with school district and state standard requirements for that grade level. Many components of GIS are part of the Washington state tests, even if GIS is not. The comprehensive integration of other subjects with the associated science gives students many avenues to contribute to a project in ways that interest them.

As a result of the success of the Adopt-a-Farmer project, students have been asked to provide presentations in state and national conferences. Travel, presentations, and networking with the professional community as well as their own community have instilled a greater confidence in these students. Even the students' parents have become more interested in participating in the education process because the program is based on local knowledge.

Continuing support by the Waterville School District administrators has allowed travel during school, helped cover substitute costs, helped find grants to cover equipment costs for fieldwork, and supported the teachers. It was also important that the mentors and the professional community provided financial support to the project to allow student travel, which has translated into success for everyone involved.

In 2006

Each fall, farmers come back to the classroom to submit their data to a new group of students. In 2006, students showed the farmers how to digitize their observations onto digital orthophotos. In the past, the farmers spent a lot of time watching students navigate to a location on the computer screen. Farmers expressed an interest in learning more about the technology, and they were given an opportunity to digitize the horny toad observations under the guidance of the fourth graders.

Several students who were fourth graders in 2005 will present a book of maps that was requested by one of the farmers. The book contains the location of all the farmers' fields. Each field is highlighted and labeled with driving instructions, crops, and other information. This GIS project was more than creating maps and learning local geographic terminology—it allowed the students and the farmer to design and develop a project together. The students will offer other farmers the same product as an after-school project.

A significant change has come to Waterville Elementary School and the surrounding community. Farmers and community members are asking for specific maps. Students who participated in the project in previous years are being solicited for these

projects. Teachers in the higher grade levels, with encouragement from school administrators, are trying to find ways to integrate these requests into their curriculum.

Students used the labeled maps as the basis for on-screen digitizing of the locations of farmers' observations using digital topographic maps in ArcView. Students, and now also the farmers, digitize observations onto digital orthophotos.

Teachers are also beginning to ask their own scientific questions and wondering if GIS can be applied to these questions. A search for more GIS mentors in the community is taking place. The supporting scientist will continue to help teachers design projects that range from bird inventories, a map of healthy and diseased trees in the city, and insect bioblitzes (i.e., quick inventories) to finding what insects horny toads eat, addressing water quality and quantity issues, and locating noxious weeds on farmers' fields. These projects will be designed through a series of continuing NatureMapping workshops.

Students that were involved in the Adopt-a-Farmer project now range from fifth graders to juniors in high school, and they are excited to get back to doing research projects. Some of these students may take over the more sophisticated aspects of the horny toad research project such as using data loggers and thermocouplers to see if horny toads do freeze in the winter.

Karen Dvornich is the cofounder and national director of the NatureMapping program in the Washington Cooperative Fish and Wildlife Research Unit at the University of Washington. She was the project assistant for the Washington Gap Analysis Project, where she was responsible for collecting all databases and datasets and led the amphibian and reptile distribution modeling efforts.

Dan Hannafious works as a fish biologist and GIS technician for the Hood Canal Salmon Enhancement Group. He is also active in outdoor education—he provides overnight camps based on salmon activities as well as summertime "bat talks" to the community. He has been associated with the NatureMapping program since 1995 and helps identify the support mechanisms needed for NatureMapping schools using GIS.

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Helping Conserve Resources in Natural Caves

Montana High School Students Incorporate GIS

By Hans Bodenhamer, Bigfork High School

Students from Browning and Bigfork high schools, both in northwestern Montana, volunteer at Glacier National Park, mapping, monitoring, and conserving resources in natural caves.

Since 2003, students from Browning and Bigfork high schools, both in northwestern Montana, have volunteered at Glacier National Park, mapping, monitoring, and conserving resources in natural caves. Recently, the project adopted a GIS component to help students manage and present their data.

Prior to using GIS, students and their teacher/ sponsor, Hans Bodenhamer, mapped and established monitoring in 13 park caves. One of these caves is more than one mile long. Cave locations were recorded using GPS, but underground surveys were completed using compasses, inclinometers, and tape measures. Cave maps were at a scale of 1:240. After drafting maps, students returned to the caves to photograph, record, and assess the natural resources in each cave. The results of monitoring efforts were drafted on maps created in Adobe Photoshop, which were explained in a series of reports submitted to the park. The number of student reports submitted since 2003 exceeds 200 pages and includes many oversized maps. One map covers two sheets, each 8 feet long by 3 feet wide.

In fall 2007, Denny Rae, GIS specialist with Flathead County, approached Bodenhamer with a proposal to incorporate GIS into his curriculum. Bodenhamer showed copies of the students' reports to Rae, who suggested that putting the data into GIS would be an excellent student project. Rae contacted Bern Szukalski, Esri's cave and karst program coordinator, who prompted Esri to donate ArcGIS 9.3 software to Bigfork High School. At that point, it became apparent that none of the school's computers were capable of running ArcGIS. For the next

year and a half, Bodenhamer applied for grants. Finally, in spring 2009, Bigfork High School received a $10,000 grant from Best Buy. This grant, one of only 15 awarded nationally, was given for its innovative proposal to use real-world technology in a K–12 setting. Using the grant, computers were purchased for a GIS cave lab at the high school.

With computers on the way, Bodenhamer contacted Ben Sainsbury, GIS specialist at Central Washington University. In 2000, as a graduate student at Northern Arizona University, Sainsbury used GIS to present 10 years of photo monitoring of cave resources in Arizona. Sainsbury volunteered to help with the students' cave project in Montana. He spent countless hours tutoring Bodenhamer in GIS and developed a procedure by which students could enter and manipulate their cave maps and monitoring data. Bodenhamer took Sainsbury's proceduresback to his students, who were eager and quickly learned the material.

In less than a month—thanks to many extracurricular hours—the students had entered most of the data that had been amassed over five years. In early June of 2009, the students presented their GIS to a gathering of about 20 park managers. The group was very impressed and suggested the student project be expanded to caves on nearby U.S. Forest Service lands and in other parks.

Bigfork High School's cave GIS uses scans of detailed cave maps, which are cleaned up and oriented using Photoshop. The cleaned-up maps are georeferenced on a topographic map as

raster images and are set to be visible below a scale of 1:800. In addition to the detailed cave maps, a filled-in vector image of the cave map is included as a separate layer. The vector image can be turned on to show the orientation of caves with respect to one another and the overlying topographic map or to provide background for the raster cave map and other layers.

Beyond raster and vector cave maps, a layer that provides general information is tied to the entrance of each cave. General information includes entrance elevation, cave length and depth, average air temperatures, and overall classification of the cave's resource significance in comparison to other caves in the region. Classified resources include biology, mineralogy, paleontology, archaeology, geology, meteorology, and hydrology. Significance classes use readily understandable terms—none, poor, fair, good, and outstanding—that are qualified in accompanying text.

Specific cave resources within each cave are also included in Bigfork High School's cave GIS. Cave temperatures, graffiti (if present), mineralogy, biology, and photo points are all included on separate layers. Points and polygons for these layers are located relative to features on the cave map. For mineralogy and biology, features are described and classified according to significance, fragility, condition, and proposed management action. Simple terms are used for each class, which are explained in accompanying text.

Acknowledgments

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Conclusion: A Closer Look at the Benefits of GIS in STEM Learning

By Joseph Kerski, Esri Education Manager

Just as STEM disciplines share such goals as using the scientific method to solve problems, employing quantitative techniques, and integrating technology, so too can GIS be used across these disciplines. GIS by its very nature is a multidisciplinary tool. Therefore, students and educators using GIS in STEM understand phenomena from a wide variety of disciplinary perspectives.

STEM prepares students for meaningful careers. Students using GIS in the classroom and in the field gain skills that will help them secure careers that are in demand in the work force. A key reason is given by the national science education standards (Center for Science, Mathematics, and Engineering Education, 1996), which state, "More and more jobs demand advanced skills, requiring that people be able to learn, reason, think creatively, make decisions, and solve problems. An understanding of science and the processes of science contributes in an essential way to these skills." Therefore, students using GIS tools are primed for STEM-based careers as wildlife biologists, soil scientists, landscape architects, civil engineers, environmental scientists, and hundreds of other positions.

Students who use GIS in tandem with STEM education develop key critical thinking skills. These skills include understanding

how to carefully evaluate and use data. By being able to ask questions of multiple datasets, students can analyze concepts and processes in a holistic fashion. Consider climate as one example. Climate underpins our agriculture, biodiversity, and our very civilization. Climatic variables are intricately tied to locations and are therefore affected by spatial relationships—of mountains to ocean currents, of depressions to soil types, of vegetation to human impact, and much more. Through GIS, students use maps, satellite images, graphs, and databases that are focused on the question of "where" to analyze patterns, trends, and influences in the past, present, and future. These spatial thinking skills may be of particular value to STEM students, as recent research suggests STEM students with strong spatial skills are more likely to experience early academic success in the field.

Every key issue of our time has a scientific component and, therefore, those issues can be examined from a STEM perspective using GIS. Moreover, investigating these topics with GIS lends relevancy and real-world contexts to the topics. Each of these issues occurs somewhere and typically occurs in multiple locations and at a variety of scales. For example, natural hazards have experienced much change in how they are perceived and managed throughout history and around the globe. The

geographic perspective is therefore important in understanding scientific issues, and GIS provides a rich toolset with which to use the geographic perspective.

Not only are STEM-based topics enhanced by GIS, but conversely, the use of GIS is enhanced by a firm grounding in STEM. This grounding provides the framework by which questions can be formulated and solutions pursued. Science is a powerful way of looking at the world; even more fundamental than the contents of each branch is the methodology. Asking questions is the first part of scientific inquiry: it forms the basis for knowing what types of social data to collect, what data to analyze, and what decisions to make.

Given the widespread concerns faced by the modern world, it is imperative that students study and understand STEM not only to equip them for life in the twenty-first century but also to ensure that we emerge at the end of the twenty-first century in a sustainable way. Experience with geospatial technology builds the integrated contextual background plus the skills in critical thinking, problem solving, communicating, and collaborating that are so vital for finding solutions to the many challenges we face.

Learn More

- Esri Education Community: edcommunity.esri.com/stem

- ArcLessons: edcommunity.esri.com/arclessons

- Esri Education on YouTube: http://www.youtube.com/esriedteam

- GIS Education Case Studies: edcommunity.esri.com/community/caseStudies/

- GIS and Science Blog: http://gisandscience.com/

- ArcGIS Online: arcgis.com

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