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Science Goes Spatial: Geotechnologies in the Classroom

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Abstract

Geospatial technology is one of the three most important emerging and rapidly evolving fields in science, business, and industry. Although geotechnologies such as Geographic Information Systems seem to be a natural fit for the classroom, many schools lag behind in introducing students to geospatial technologies. One major reason is the investment of time required for teachers to acquire and become conversant with geospatial software and to develop instructional materials that enhance student learning. This paper describes a geospatial professional development effort underway in Montana entitled Science Goes Spatial: Geotechnologies in the Classroom (GTEC). The GTEC project identifies critical system supports for teachers, models effective and developmentally appropriate uses of emerging geospatial technologies, builds leadership teams within and across school districts, and shares the possibilities of geotechnologies through the establishment of an online interactive spatial data portal.

Globalization and the US Economy

> *America's economic strength and global leadership depend in large measure on our Nation's ability to generate and harness the latest in scientific and technological developments and to apply these developments to real world applications (American Competitiveness Initiatve, 2006).*

The American Competitiveness Initiative, authored by the US Domestic Policy Council and the US Office of Science and Technology, has pledged to commit "$5.9 billion federal dollars in fiscal year 2007 and more than $136 billion over a ten year period to increase investments in research and development, strengthen education, and encourage entrepreneurship and innovation." Why is the US government investing billions of dollars to promote a science and technology work-force development agenda? What are the most important components of this policy and how will it affect those of us in the K-12 educational arena?

This paper proposes answers to these questions and describes a geospatial professional development effort underway

in Montana entitled *Science Goes Spatial: Geotechnologies in the Classroom* (GTEC). Spearheaded by The University of Montana School of Education, the GTEC project is designed to support teachers in their efforts to create innovative, technology-rich classroom learning environments.

In 2005, the National Academy of Sciences (NAS) reported, "Having reviewed trends in the U.S. and abroad, the committee is deeply concerned that the scientific and technical building blocks of our economic leadership are eroding away at a time when many other nations are gathering strength." Two years later, the NAS (2007) released yet another report on globalization and the US economy insisting that the US must significantly increase its commitment to the development, recruitment, and retention of top students, scientists, and engineers in order to ensure its leadership as the "premier place in the world for innovation." This federal appeal to create and maintain US intellectual capital clearly identifies education as the first line of defense in ensuring the US has a reliable source of "knowledge workers." Indeed, holding teachers and schools accountable for the economic future of the US is a perennial favorite among politicians and the media.

Thomas Friedman's recent and controversial bestselling book The World is Flat delineates in everyday language what this federal entreaty might mean for educators. Friedman begins by pointing to Princeton economist Alan Blinder's argument that "*how* we educate our children is more important than *how much* we educate them." Friedman's anecdotal observations addressing globalization and the need for a well educated US workforce are best summed up in a dinner conversation he describes with his daughters;

> *Girls, when I was growing up, my parents used to say to me, "Tom, finish your dinner – people in China and India are starving.' My advice to you is: Girls, finish your homework – people in China and India are starving for your jobs.*

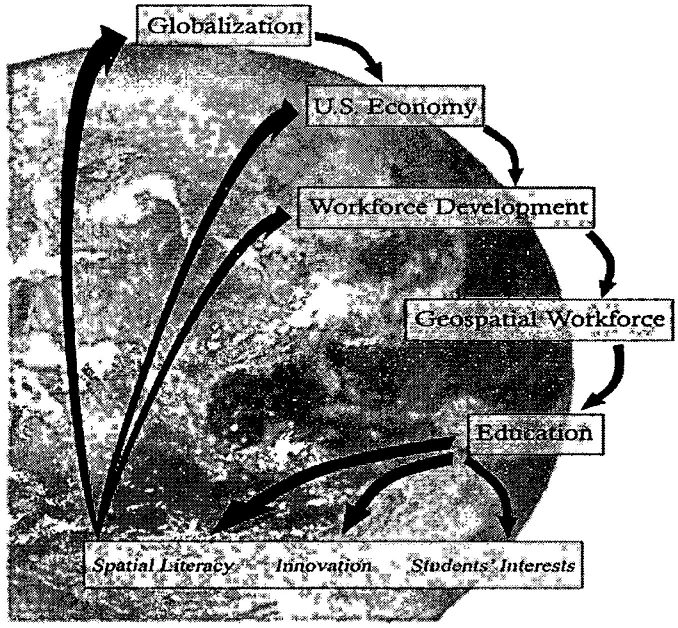
Geospatial Workforce Development, Geospatial Technologies and Education

For what kinds of jobs are people in China and India starving? A US Department of Labor (DOL) report answers this question. In 2003, the DOL published a list identifying 14 job sectors that were adding substantial numbers of new jobs and/or being transformed by technology and innovation requiring new skill sets for workers.

One of the 14 job sectors identified was the geospatial technology industry. In 2003, Gaudet, Annulis, and Carr estimated the current geotechnologies market at $5 billion and projected it to be a $30 billion market in 2005. In 2004, US Secretary of Labor Elaine L. Chao issued a report announcing a series of investments totaling more than $6.4 million to address the workforce needs of the geospatial technology industry (U.S. Department of Labor, 2004).

Shortly after (and perhaps not coincidentally) Chao released her report addressing workforce needs, the National Research Council (NRC) released a report highlighting the need for K-12 schools to teach spatial thinking - skills that are facilitated when solving real-world problems using geospatial technologies. Spatial literacy, argued the NRC, must be recognized along with other basic academic skill sets – ***maps, pictures, and spatial data** need to rank with **numbers, text, and logic** as essential ways in which humans function, the fourth "R"* (Goodchild, 2006).

According to the NRC (2006), instruction in spatial thinking will foster a new generation of spatially literate students proficient in terms of spatial knowledge, spatial ways of thinking and acting, and spatial capabilities:



Spatial literacy would not be an add-on to an already overburdened school curriculum; but, rather a missing link across the curriculum and a lever to enable students to achieve a deeper and more insightful understanding of subjects across the curriculum. . .spatial thinking must be recognized as a fundamental part of K-12 education and as an integrator and a facilitator for problem solving across the curriculum. With advances in computing technologies and the increasing availability of geospatial data, spatial thinking will play a significant role in the information- based economy of the 21st-century.

Not only are spatial data becoming more prevalent, the tools used to manipulate spatial data are becoming more intuitive and easy to use. The emergence of geotechnologies (satellite imagery, global positioning systems, GIS, and other spatial software) is revolutionizing how scientists interpret and use data.

Because of their great analytical power, geographic information systems are currently used as a research and planning tool for numerous business and industrial applications. In fact, GIS analysis is used daily in so many aspects of human life that Alibrandi (2003) predicts it will one day be a required basic skill set just as word processing is today.

If you have ever accessed a travel map from the internet, you have benefitted from GIS. In watching last night's weather program, you viewed a geographic information system. Simply put, geographic information systems are the most efficient and powerful way to organize, analyze, and display spatially linked data. For these reasons, GIS and **Figure One** spatial thinking are predicted to play an essential role in K–12 education, and in the rapidly increasing US and global job market (Figure One) US Classrooms and the Global Economy

Are US classrooms obligated to provide opportunities for students to develop spatial literacy skills based on the argument that the development of these skills confers an economic advantage for students (and, as a result, for the US economy)? The answer to this question is grounded in how one defines the purpose of education. Those vested in an educational system that sees students as a future workforce would agree that the US classroom plays a vital role in our economy.

Those individuals who see education as a means to leading a successful and fulfilling life (as defined by the individual and not the government) may not agree. Regardless of one's view on whether economic policy should dictate educational decisions, it is recognized that educating for innovation, higher order thinking skills, and informed decision making can benefit both a knowledge-based economy and the individual (New Commission on the Skills of the American Workforce, 2005).

Geotechnologies such as GIS are "foremost tools to make decisions" (Kolvoord, 2005). While it is true that technology alone will not move the student to higher-order thinking skills, applications such as GIS are well-suited to this charge, offering significant opportunities to interact with real-world data and complex problems. GIS eliminates intellectual passivity, "stimulates students' intellectual development, and enables the learner to create, revise, and reconstruct what they know to create new frameworks of knowledge" (Burns, 2006). Teachers can effectively integrate GIS into a variety of content areas and assist students in the use of geotechnologies as tools for identifying patterns and trends, making authentic decisions, using real-time data, and facilitating a better understanding of their world.

Science Goes Spatial: Geotechnologies in the Classroom

Although GIS seems a natural fit for the classroom, many schools lag behind in introducing students to geospatial technologies. A major reason is the investment of time required for teachers to acquire and become conversant with geospatial software and to develop instructional materials that enhance student science learning (Kerski, 2003; Meyer et al., 1999).

Montana is unique in that it was the first state to secure a statewide GIS software license for schools, although it is now one of a fast growing number of states that hold similar statewide GIS software school licenses. Unfortunately, experience has shown that access to software alone does not guarantee that teachers will include GIS as part of their classroom teaching, as other barriers exist to implementing these programs in the classroom. The following sections describe a program that was established in Montana specifically to address those barriers and facilitate spatial literacy in the classroom.

For the past five years, The University of Montana School of Education (UMSoE) leveraged the Montana state software license for schools by providing geospatial teacher training to 234 participating schools as part of the GIS4MT initiative. In follow-up program evaluation studies of the geospatial trainings it was found that teachers struggled to fully implement geotechnologies into their classrooms, citing a lack of access to spatial data sets appropriate for school-aged audiences and onsite support as the two main barriers to implementation.

In response, the UMSoE launched the *Science Goes Spatial: Geotechnologies in the Classroom Project (GTEC)*. Funded by a Toyota USA grant, the GTEC project is a professional development program that models effective and developmentally appropriate use of emerging

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geospatial technologies, builds leadership teams within and across school districts, and shares the possibilities of geotechnologies through the establishment of an online interactive spatial data portal.

Applications for participation in the GTEC program were only sent to GIS4MT teachers participants as their completion of the GIS4MT trainings indicated both a strong interest in geotechnologies and a growing competency in the use of geotechnologies. From 234 teacher candidates, 20 teachers were selected for participation in the GTEC project. The goal of the teacher recruitment process was to select a *geographically diverse* set of Montana teachers who were identified as leaders within their school communities in the use of geospatial technologies. Teachers were selected based on the following criteria:

1. Number of years as a classroom teacher;
2. Amount and depth of training in the use of geotechnologies;
3. Evidence of successful use of geotechnologies with students; and,
4. Support and recognition by school administration.

Once selected, teachers signed a contract detailing program expectations and responsibilities for the respective academic year (Cohort One: 2006-2007 or Cohort Two: 2007-2008). Figure Two outlines the participating GTEC schools.

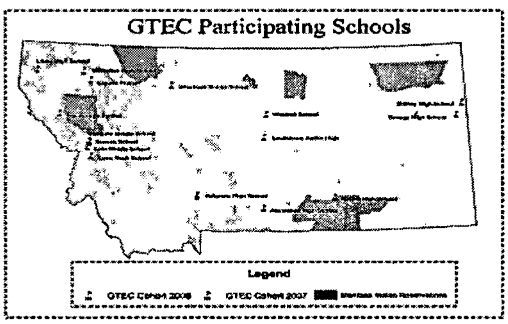


Figure Two: GTEC Participating Schools

Each teacher cohort participated in a week-long geotechnologies summer institute designed to introduce teachers to spatial data sets produced and in use by research scientists. Each teacher was then responsible for developing and implementing a GIS curriculum module with accompanying spatial data sets which are made available on the project website after being field tested.

Teachers left the institutes excited about GIS and with new knowledge. Below is a sampling of what teachers reported learning during the summer intensive sessions:

- How to operate the ArcView program, Google Earth tours, GPS;
- I learned varied and numerous activities in which GIS could potentially be used;
- That making the map and using the software is very secondary to the ability to analyze the map that is created;
- How to find and manipulate different data bases;
- How others are tackling the data problems;
- Getting to know people and networking;

- Importing waypoints and tracks;
- I'm absolutely serious when I say I feel I will be able to use everything we learned when I get home and I'm excited to go home and teach my kids about this;

Given the amount and depth of learning by participating teachers, the next and potentially difficult step was implementing and integrating this new technology into the classroom. The sophistication of this powerful technology poses special challenges to teachers. Teachers anticipated facing the following challenges as they worked toward helping their students attain spatial literacy:

- Remembering the lesser used commands;
- With the advent of Google Earth we have a new powerful tool but another facet to teach. It all just requires commitment;
- Finding data that is useful to my students;
- Will the software run effectively on our school's platform?
- Having the time to develop mini-lessons for each of the units in my curriculum and have them ready when the school year starts;
- I believe that my other teaching activities may interfere with my pursuit of GIS perfection. I would love to include a GIS component in all of my classes, but time and lack of available computers might make it difficult;
- Being successful in getting students involved with inquiry learning. Although that is not maybe the responsibility of GTEC, but it is ultimately my goal.

To support teachers in the development and implementation of their spatial data sets and curriculum throughout the academic year, GTEC project leaders created several system supports. First, an interactive website and spatial data portal for teachers was developed. Second, synchronous chats were held four times a year for past and current GTEC teachers and project staff to monitor classroom implementation, introduces new teaching strategies and resources, and further facilitate teacher communication across project sites and cohorts. Third, GTEC staff piloted new, interactive teaching software for tutorial animation to enhance student understanding and retention. Fourth, GTEC project staff held regularly scheduled help desk hours to provide answers to questions and further ideas for curriculum development. Additional details of these system supports are provided below.

Interactive Website and Spatial Data Portal (www.spatialsce.net).

During development of the program website, the GTEC project was envisioned to be one that would expand in scope and depth as teachers' geotechnologies needs evolved. Consequently, the entry page to the website is entitled Spatial Sci (Figure Three), the parent program for multiple geotechnologies resources within the site. The GTEC project has its own set of pages within the parent Spatial Sci website, which can be accessed by the user under the **Programs** tab.

Some of the most important features of the website are the data and image portals. Under the **Data** tab, users can find five categories of spatial data: *demography, physical science, life science, earth science and Google Earth data layers (Figure Four).* These categories, designed to complement established classroom content areas, were developed based on focus groups held with teachers across Montana who regularly and successfully incorporate geotechnologies into their teaching.

When a user clicks on one of data category tabs, all of the spatial data layers available for that content domain are displayed using consistent data formats and map projections. With the exception of Google Earth data layers, which are specific to that software platform, all other data layers are designed to be used with ESRI's ArcMap GIS and mapping software platform (www.esri.com). A keyword search is also offered for teachers who are interested in accessing data related to a specific concept (e.g., glaciers). Users can also visit the **Imagery** tab for aerial and satellite imagery.

Under the **Curriculum** tab, users can access the curriculum pieces developed and piloted by GTEC participants and staff, and other geotechnology efforts under the direction of GTEC project leaders. Under the **Resources** tab, the user can access the synchronous chat feature to meet online in a chat room. This feature is also used to bring GTEC teachers together for further professional development and networking opportunities.

Skill builders and **Video vignettes** are online tutorials that highlight particular geotechnologies; for example, teachers and their students can access and follow a lesson on importing GPS waypoints into ArcMap. When clicking on the **Links** page, users will find a current list of hyperlinks connecting teachers to supporting online resources.

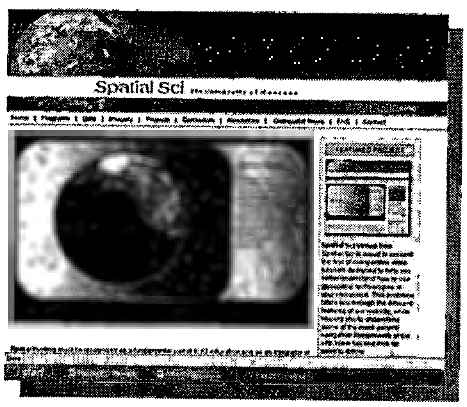


Figure Three: Spatial Sci Website

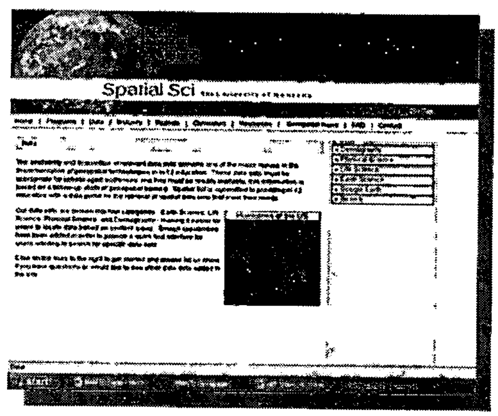


Figure Four: Data Portal

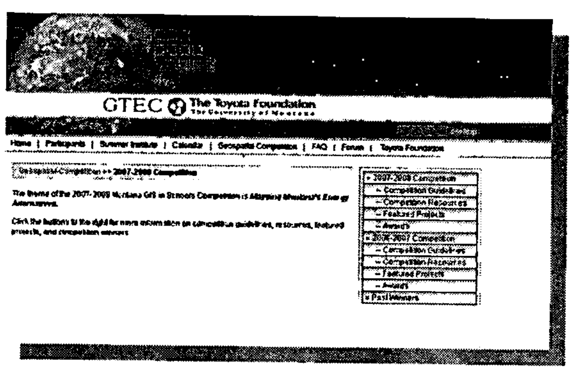


Figure Five: GIS Competition

GIS Competition

One of the avenues for dissemination of the GTEC project goals was the development of a statewide GIS competition. The theme for the first annual GIS competition (2006) was *Montana's Changing Snowpack and What it Means for your Community. The 2007 GIS Competition is entitled Mapping Montana's Energy Alternatives*. Teachers can download the competition guidelines and entry forms, access competition resources, download projects, and view award winners by clicking on the **GIS Competition** tab (Figure Five).

GTEC Help Desk

GTEC teachers can contact GTEC project staff via phone or email and expect an immediate and knowledgeable response to their geotechnologies questions. This service proved very useful for teacher participants, both in terms of furthering geospatial curriculum development and for identifying GIS training needs

GTEC Project Evaluation

Project evaluation focuses on the extent to which participating teachers increase their spatial literacy knowledge and their use of inquiry-based pedagogy to engage students in geospatial activities; and the extent to which students increase their spatial literacy and knowledge and interest in geospatial concepts and careers. Students complete two instruments as pre- and post- measures:

1. **Spatial Literacy Assessment** (developed by the Association of American Geographers and used by permission). This instrument contains 16 items that measure skills and knowledge associated with geospatial literacy.

2. **Science Interest Survey** This instrument probes beliefs with respect to science and geospatial technologies and perceptions about related career options. The survey was developed by project staff based on a variety of sources dealing with standards in geosciences and asks students a series of questions which yield beliefs about and interest in science as well as in geospatial content and careers.

Teachers complete a pre- and post-Spatial Literacy Assessment, participate in an onsite visit by GTEC project staff, and submit the following artifacts: 1) GIS spatial data set and supporting curriculum; 2) Classroom videotape showing implementation of the GIS curriculum with students; and, 3) Student work samples.

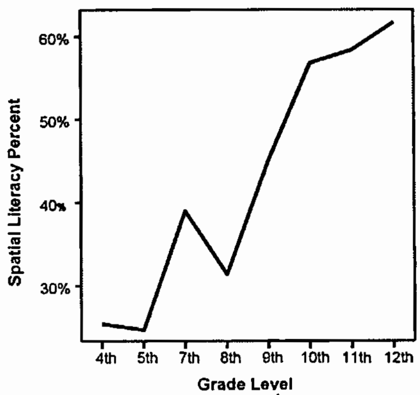
This report discusses the results of the baseline assessments of both teachers and students in Cohort 1 (academic year 2006-07) as well as those Cohort 2 teachers and students that have submitted data.

Spatial Literacy Results

On average, Cohort 1 teachers answered 12 of the 16 questions on the spatial literacy assessment correctly (low: 10 of 16; high: 15 of 16). By comparison, Cohort 2 answered 11 questions correctly on average (low: 9/16; high: 13/16). Student scores, on the other hand, varied considerably from a low of 28% correct (roughly 5 out of 16 correct) to a high of 82% or 13 out of 16 correct. On this baseline assessment the most significant predictor of score on the spatial literacy assessment was grade level (Pearson correlation = .530; $p<.01$). In other words, the higher the grade level, the better the score. Chart

One below illustrates the relationship between grade level and spatial literacy score.

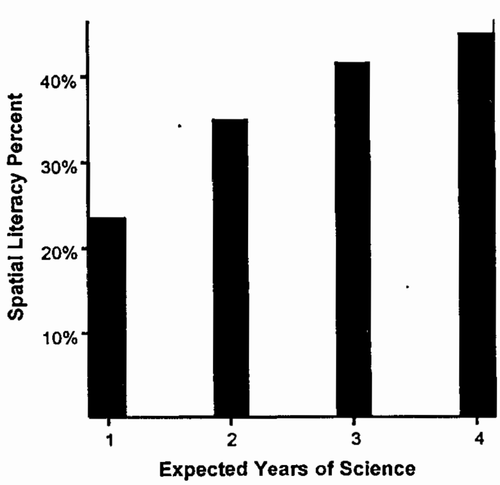
Chart One: Student Spatial Literacy Scores by Grade Level



Note the steep rise from elementary to middle school and from middle school to high school. The dip from 7th to 8th grade may be due to the fact that 8th graders who took the survey were in a history class while the rest of the students were science classes. The poor performance at the elementary and middle school levels may also be an artifact of the spatial literacy assessment target audience (i.e., it may not be appropriate for grades lower than 9th grade).

Students were asked to estimate the number of years of science that they expected to have completed by the time they finished high school. Data indicates that the more science students expect to take in high school, the better they scored on the spatial literacy assessment (Chart II).

Chart II: Literacy Score by Expected Years of Science



No significant differences were detectable in the assessment data due to gender or ethnicity, and student mean scores on the assessment were not correlated with teacher scores. In fact, female and male students scored within 1% of each other on the assessment. While Table One contains a wide range of assessment scores for each ethnic group, because each group is small in comparison to the "White" group (both within and across cohorts) it is impossible to conclude that these differences are significant.

Table One: Spatial Literacy Percent Score by Ethnicity

			Cohort	
			1	2
Ethnicity	African American	Percent Score	71%	N/A.
	Asian	“” “”	47%	N/A.
	Hispanic	“” “”	47%	26%
	Native American	“” “”	31%	53%
	White	“” “”	43%	36%
	Other	“” “”	29%	50%
	Do not wish to answer	“” “”	44%	29%

Science Interest Survey Results

The Science Interest Survey was divided into two parts. The first part contained 20 questions about beliefs with respect to science (10 items) and geospatial technologies (10 items). All items used a Likert scale (1 = disagree strongly, 2 = disagree, 3 = no opinion, 4 = agree, 5 = agree strongly). The science items were averaged to produce a "science beliefs" score and the geospatial items were average to produce a "geospatial technology beliefs" score. The goal was to get a sense of GTEC student attitudes in terms of personal beliefs about science and geospatial technologies.

The average science beliefs score across all subjects was 3.4 and the average score for beliefs about geospatial technology was about 3.5 (see Table Two). Not surprisingly, interest in science was highly correlated with interest in geospatial technologies (Pearson correlation = .616; $p<.001$).

Table Two: Spatial Literacy Percent Score by Ethnicity

	N	Mean	Std. Deviation
Science Beliefs	265	3.36	.62302
Geospatial Technology Beliefs	266	3.46	.54071
Valid N	265		

The science beliefs items that were most highly rated were: "Learning science will improve my career chances," "I think science is exciting," and "Science is useful for solving problems in my everyday life." The highest rated items concerning beliefs about geospatial technologies were "The use of computer maps will be important to me in my job some day," "I like using the computer to create maps," "Satellites, GPS devices and remote sensing equipment are cool," "I like to use maps to answer questions about people and places," and "I like to think about how to solve environmental problems."

Science and geospatial technology beliefs were not significantly related to gender, grade level, ethnicity, or which cohort they were in. Neither beliefs about science nor geospatial technologies predicted student scores on the spatial literacy assessment.

The second part of the survey asked students to think about how much they would like to engage in specific tasks or activities related to geospatial and biotechnology careers. The average ratings for interest in engaging in activities related to geospatial careers was 3.0; for biotechnology it was 3.2. That is, interest in doing biotechnology or geospatial career tasks was, on average, fairly neutral. However, because the list of career tasks (15 each for biotechnology and geospatial technology) covers a wide range of different tasks it is not surprising that there was a correspondingly wide range of responses. Thus, it is more instructive to look at individual items to see where student career interests were more specifically focused. Table III presents the rank order of items from highest to lowest.

Notice that of the highest ranked 15 items, only 4 dealt with geospatial technologies. Moreover, the highest rated geospatial technology career task had a mean rating of 3.22, just slightly toward the "agree" pole. Likewise, 11 of the 15 lowest rated career tasks also dealt with geospatial technologies. In fact, students disagreed with the idea of engaging in 6 geospatial career tasks in their jobs some day (i.e., mean rating < 3.0). Since these are baseline data and students had not yet been exposed to extensive GIS instruction (i.e., as a result of the GTEC project) these results are to be expected. One indicator of success will be the extent to which the ratings of any or all of these items increases on the post assessment as compared to this baseline.

A rich set of baseline data has been collected for teachers and students from both cohorts. Current data indicates that both cohorts are similar in terms of most of the baseline data. Some trends are apparent in the data. Spatial literacy assessment scores tend to increase with grade level, and gender, ethnicity, and teacher score on the literacy assessment do not seem to have any appreciable impact on student assessment scores.

Conclusion

The US government is investing billions of dollars promoting a science and technology work-force development policy because, on a global scale, technologies such as GIS are critical emerging and rapidly evolving applications in science, business, and industry. In the classroom, geospatial technologies enable students to

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examine spatial relationships, access and analyze authentic and complex data sets from a local to a global scale, and make decisions regarding important environmental, social, and scientific issues. While geospatial technologies such as GIS are highly motivating for teachers and students, the complexity of learning how to use the technology and effectively integrate applications into classroom teaching takes time, effort, and ongoing professional development. Successful professional development models should include system supports that provide regularly available software and hardware technical assistance and developmentally appropriate spatial data sets and curriculum aligned with national and state content standards.

Table III: Rank Order of Career Activities

	Career Activity	Career	Mean
1	Use clues from crime scenes to solve murder mysteries.	Biotech.	3.67
2	Discover cures for diseases like cancer.	Biotech.	3.63
3	Experiment with new ways to improve foods.	Biotech.	3.32
4	Create new drugs to treat diseases.	Biotech.	3.29
5	Invent substances used to make new products.	Biotech.	3.29
6	Design a satellite that takes super high-definition pictures of the earth.	Geospatial	3.22
7	Work with test tubes, pipettes, beakers & other equipment in a laboratory.	Biotech.	3.21
8	Alter DNA to change the characteristics of plants and animals.	Biotech.	3.20
9	Design a way to check for food poisons.	Biotech.	3.19
10	Use computers to study the genetic code of living things.	Biotech.	3.16
11	Work with city planners to help businesses decide where to put their buildings.	Geospatial	3.16
12	Use special cameras to study the surface of the earth in three dimensions.	Geospatial	3.11
13	Use a GPS device to record the locations of earthquakes and tornados.	Geospatial	3.09
14	Design and perform biotech experiments in a laboratory.	Biotech.	3.08
15	Develop methods to detect bio-warfare agents such as anthrax.	Biotech.	3.08
16	Analyze images of the earth taken from satellites.	Geospatial	3.06
17	Write computer programs to predict where forest fires might occur.	Geospatial	3.04
18	Design high tech devices like GPS units and Personal Digital Devices.	Geospatial	3.04
19	Design roads, rail systems, and other parts of a city.	Geospatial	3.01
20	Use maps and databases to see where people from different cultures live.	Geospatial	3.00
21	Prepare biological materials for use in research.	Biotech.	2.95
22	Perform genetic tests to trace the evolution of plants and animals.	Biotech.	2.92
23	Devise new ways to use bacteria and other microorganisms.	Biotech.	2.91
24	Design computer models to explain how the earth has changed over time.	Geospatial	2.91
25	Develop computer software that creates interactive maps.	Geospatial	2.89
26	Study weather patterns on computer maps to see if climate change is occurring.	Geospatial	2.89
27	Use maps and databases to plan the best possible uses for our land.	Geospatial	2.86
28	Maintain and troubleshoot equipment used in making products.	Biotech.	2.85
29	Teach others how to use mapping programs on the computer.	Geospatial	2.77
30	Work on a team to find out the height of hills and mountains.	Geospatial	2.62

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