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Using Geospatial Technology to Enhance Science Teaching and Learning: A Case Study for 'SATELLITES' Geo-science Program

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ABSTRACT

This paper describes how researchers and teachers have developed ways of embedding the 'SATELLITES' geo-science and technology education program into K-12 classrooms, to enhance science teaching and learning. SATELLITES (Students And Teachers Exploring Local Landscapes to Interpret The Earth from Space) is a professional development program aimed at enhancing handson science and technology education in a wide range of thematic areas, including Earth and Space Science, Geography, Environmental Science, Biology and Physics. Since the Program's beginning in 1998, hundreds of teachers have attended intensive summer professional development Institutes in Earth Science and Technology content, project-based learning (PBL), and student inquiry. By leveraging the GLOBE (Global Learning and Observations to Benefit the Environment) Program's outreach and education resources, thousands of students from across the US and several other countries have participated in SATELLITES. The assessments performed on the efficacy of the program have clearly showed a positive change in teachers' level and quality of knowledge in geo-technologies and related natural sciences and in students' engagement in science and comprehension of science concepts. The experience gained throughout the program's long life has allowed the development and implementation of guidelines and recommendations to address emerging challenges. These experiences, together with the effective overall performance of the program create an important potential to expand its impact, by building capacity in more areas of the country or in other countries, where geospatial technologies have not yet been systematically introduced in the school environment.

Keywords: geospatial technology, STEM, inquiry-based teaching and learning, GLOBE, international collaboration

INTRODUCTION

Effective formal science education is a significant challenge in many countries, despite the amount of rhetoric, effort, and funding devoted to it (Parliamentary Assembly, Council of Europe, 2013). STEM (Science, Technology, Engineering and Mathematics) education in formal school settings does not consistently promote some of the core values and practices of science and engineering in practice; namely, searching for uncertainty,

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Figure 1. Average performance refers to all 15-year-old students in a country/economy regardless of the school type and grade attended. Small differences between countries and over time may be statistically insignificant. Adopted from: PISA 2015 at: http://www.compareyourcountry.org/pisa/country/USA?lg=en).

recognizing ambiguity, and learning from failure (US Department of Education, 2016). There are many reasons for this, but some that are often identified are: curriculum and time limitations, the wide and increasingly complex and interdisciplinary range of the content areas and inadequate teacher professional development required for teachers to stay current (Dib, 1988).

These challenges take on added importance when one considers that the improvement of science education quality at all levels is important not only in the classroom, but also in the wider context of contemporary societies facing serious environmental and other types of crises. The worldwide decrease of interest in science education is a serious challenge (Royal Society, 2008a) and there are well-documented studies of declining interest in science and science careers in primary (Jarvis & Pell, 2002) and secondary schools (Royal Society, 2008b; Sturman & Rudduck, 2009; TIMSS, 2008). The STEM pipeline in the US leaves too many students without access to quality STEM education and with neither the interest in nor the ability to obtain a degree or work in STEM fields (U.S. Congress Joint Economic Committee Chairman's Staff (2012, April). Recently released data from international math and science assessments indicate that U.S. students continue to rank around the middle of the pack, and behind many other advanced industrial nations. One of the biggest crossnational tests is the Program for International Student Assessment (PISA), which every three years measures reading ability, math and science literacy and other key skills among 15-year-olds in dozens of developed and developing countries. The most recent PISA results, from 2015, placed the U.S. an unimpressive 38th out of 71 countries in math and 24th in science. Among the 35 members of the Organization for Economic Cooperation and Development, which sponsors the PISA initiative, the U.S. ranked 30th in math and 19th in science. (Pew Research Center, 2017) (Figure 1).

Furthermore, although the percentages of US teachers that lack adequate discipline-specific hands-on training is low (7% for high-school biology and life sciences teachers, 18% for high-school physical sciences teachers, and 12% for high-school math teachers (National Science Foundation, 2012)), many do not possess adequate experience working with STEM in a Project-Based Learning (PBL), student-inquiry pedagogy (National Research Council, 2011).

According to recent reports of the National Association of Educational Progress (NAEP, 2015), in 2015, twenty-two percent of twelfth-grade students performed at or above the Proficient level on the science assessment compared to 21 percent of students in 2009, the previous assessment year. This apparent one-percentage point difference was not statistically significant. Also, in comparison to 2009, there were no significant differences in the percentage of twelfth-graders who performed at or above the Basic level or below the Basic level in 2015. Proficient on NAEP assessments means that students demonstrate solid academic performance and competency over challenging subject matter.

Much research has been conducted to understand and improve teaching approaches that engage students and facilitate better understandings of science content knowledge. Despite all the relevant research, science educators are challenged to develop engaging teaching methods that help their students make conceptual changes in their scientific thinking and acquire new information that they may critically appraise and utilize in order to acquire knowledge (Adaktilou et al., 2011). Project based learning (PBL), the approach to teaching in which students get to explore real-world problems and challenges and develop cross-curriculum skills, has been shown to inspire and engage students and give them ownership of their own learning. Research also indicates that students are more likely to retain the knowledge gained through this approach far more readily than through traditional textbook-centered learning. In addition, students develop confidence and self-direction as they move through both team-based and independent work. In the process of completing their projects, students exercise their organizational and research skills, develop better communication with their peers and adults, and often work within their community while seeing the positive effect of their work. (Edutopia, 2008).

PBL and student-inquiry pedagogy define the framework within which teachers implement the SATELLITES program.

The explosion of digital technology has created great potential and expectations in the delivery of the science education classes. Yet, although many teachers are genuinely interested in using the technologies to enhance teaching and learning, these technologies come at a cost – they need to be 'learned' first by the teachers in order to confidently and effectively use them in their teaching. For example, computers were introduced in schools as powerful and flexible tools to support the learning process, but many teachers mainly used them as delivery tools to present instructional content or to engage students in the use of computerassisted learning applications such as drill and practice, tutorials, and simulations (O'Dwyer et al., 2004; Smeets, 2005, as cited in Inan et al., 2010). Providing teachers and students with easy access to computer technology is only the first step toward using technology as an effective instructional and learning tool (Silvernail & Buffington, 2009). Several examples of technology-based applications effectively illustrate various ways in which technology can enhance how students learn by supporting four fundamental characteristics of learning: (1) active engagement, (2) participation in groups, (3) frequent interaction and feedback, and (4) connections to real world contexts (Rochelle et al., 2000). Professional development opportunities for teachers can provide the guidelines and recommendations that teachers need in order to effectively pursue the above. Professional development, supported by ongoing help as the teachers use the new technologies, is a main principle of SATELLITES.

The discipline of Earth system science, characterized by complex, interdisciplinary content, problemsolving, inquiry-based learning, laboratory demonstrations, hands-on data collection procedures, and data analysis, provides an excellent opportunity to integrate technology into science education. Earth System Science is an interdisciplinary domain defined as the formal scientific study of the Earth as a single integrated system that cycles energy and matter through the atmosphere, hydrosphere, biosphere and geosphere (American Geophysical Union, 1996).

Technology has always played an important role in Earth science and in Earth science education. Contemporary Earth system science technology, for example remote sensing and geographic information systems (GIS), make it possible to understand aspects of our dynamic global environment, from natural and anthropogenic changes in land cover and sea level, to changes in the climate and atmosphere and changes in socio-demographic measures driven by immigration and disease (Landenberger et al., 2006). Monitoring environmental changes that affect the quality of life, such as the urban heat island effect in metropolitan areas or desertification in arid regions of the world, is crucial to make informed decisions about the future.

Technology is an essential tool in environmental decision-making, and is completely integrated into modern society. But where is technology's place -with respect to environmental applications- in the classroom, where young students and future decision makers get their instruction? What are the characteristics of a successful geo- technology instruction pedagogy? Are these characteristics themselves teachable to teachers? Further on in this paper, applications of technology in science education in the framework of the SATELLITES program will be addressed.

GEOSPATIAL TECHNOLOGY IN EDUCATION

The technology used to accomplish the visualization, measurement and analysis of features or phenomena that occur on the Earth, including its landforms, climate and infrastructure is referred to as 'Geospatial Technology' (Munro-Stasiuk et al., 2006). Geospatial technology encompasses Geographic Information Systems (GIS), Global Positioning Systems (GPS), and Remote Sensing (RS), all three of which are tools that facilitate the collection, analysis and interpretation of spatial data (US Department of Labor, 2005a). Remote Sensing, the art and science of obtaining objective quantifiable information about an object without being in contact with it (Lillesand & Kiefer, 1996), provides a wide range of very interesting and powerful data that

allow its users to have a better understanding of the enormous and complex challenges involved in managing the environment. With the advent of GPS, exact three-dimensional coordinates of objects on the Earth's surface can be collected, stored, organized, shared, and analyzed. Much of the data now available, either from remote sensing or from in situ measurements, can be accessed and utilized by almost anyone through increasingly easy to use and often free GIS software.

Geospatial technology has been introduced in higher education relatively lately, so it is not surprising that it has not been widely introduced in K-12 classrooms worldwide. The digital-earth.eu project 'Needs Analysis Report' (Digital Agenda for Europe initiative, 2010) confirmed that in European education, there had been little or no attention to using emerging geospatial technologies in European schools. The US National Science Foundation (NSF) awarded a \$2.2 million grant to National Geographic, the National Council for Geographic Education (NCGE), the Association of American Geographers (AAG) and the American Geographic Society to collaboratively develop a 'roadmap' to implement the 21st Century Geography-Geospatial Education (National Geospatial Advisory Committee, 2012).

At this point, there are several US and European geospatial education pilot projects, but large-scale implementation does not yet exist in a systematic way. According to research concerning the STEM and related geospatial science and technology education situation in US schools, the use of GIS in the 1990s in K-12 classrooms had grown very little (Donaldson, 2000; Kerski, 2000). Of the approximately 1,900 US high school classrooms that had a desktop GIS at that time, less than 15 percent reported ever using it for instructional purposes (Kerski, 2000). These results have been presented at the first conference on Educational Applications of GIS [EDGIS] in 1994 (EDGIS, 1994; Palladino, 1994). References from more recent research indicate that this situation has not changed dramatically. For example as quoted in Donert (2013): 'European school education has so far, by and large, ignored geospatial developments like remote sensing, despite the fact that geo-technology has already become a significant employer. There are small pockets of intense activity, the challenge is to scale these developments up'. Also the recent National Assessment of Educational Progress in Geography revealed that few American students can identify locations of current events, the scale of those events, or why those events are important. Social studies educators have found that by incorporating emerging technologies into their classroom such as Geographic Information Systems (GIS) and the Global Positioning System (GPS)-students can improve their geography engagement, content knowledge, and skills. Adoption of geospatial technologies has been slow in the United States but is gaining some momentum worldwide (Milson & Kerski, 2012).

The importance of understanding geospatial technology is highlighted by the fact that this industry is one of the leading job sectors identified by the US Department of Labor (2003) to: (a) add substantial numbers of new jobs to the economy or affect the growth of other industries, (b) support existing or emerging businesses that are transformed by technology and innovation, requiring new skill sets for workers. According to 2004 research, 175,000 people were employed in the US in the remote sensing and geospatial information industry, including commercial firms, non-profit organizations, government agencies, and academic institutions (Mondello et al., 2004). According to the US Bureau of Labor Statistics, there were a total of 262,627 US geoscientist jobs in 2008, and in 2018, the projected number of US geoscientist jobs is 322,683, a 23 percent increase. The increase in job growth varies among industry sectors, with the professional, scientific, and technical services industry having the highest geoscience job growth (50 percent). Even with predicted attrition, aggregate job projections are expected to increase by 35 percent between 2008 and 2018 (American Geoscientists Institute, 2011). However, according to Gaudet, Annulis, and Carr (2003) there are more positions in the US that have a geospatial skills requirement than there are people to fill them. The US National Center for O*NET (Occupation*New and Emerging Technologies) Development reported that a recent survey of geospatial products and service providers revealed that 87% of the respondents had difficulty filling positions requiring geospatial technology skills (Du Plessis & Van Niekerk, 2011).

It is also interesting to state that with respect to research, in 2009, U.S. Scientists fielded nearly 29 percent of research papers in the most influential journals, compared with 40 percent in 1981. The STEM crisis is causing a reduction in research, which restricts growth. By 2009, for the first time, over half of U.S. Patents were awarded to non-U.S. companies because STEM shortcomings are forcing a hold on innovation (National Math and Science Initiative, 2016).

These facts reflect the necessity to build an education and training system with the capacity to raise awareness of the utility of geospatial technology and the many opportunities in the geospatial sector, as well as to create a geo-spatially 'literate' work force and citizens who benefit from the advances in science and technology. The priority in this area should clearly be to facilitate integration of geospatial science and technology early into K-12 classrooms around the world, so that the global citizenry is geo -spatially literate and has the spatial thinking skills necessary to frame and understand the complex environmental and social challenges that we face.

Spatial literacy, also referred to as "spatial thinking", is the ability to use the properties of space to communicate, to reason, and to solve problems (NRC, 2006). Using space (and time) to frame and understand various phenomena is essential to understanding complex natural and human systems. Goodchild (2006) states "...that maps, pictures and spatial data need to rank with numbers, text and logic as essential ways in which humans function, both on and off the job, as they reason, interact and generally live their lives." The US National Research Council (2006) recommended that spatial literacy should not be an add-on to the school curriculum, but an essential link in the curriculum and a means that can enable students to get a deeper understanding of many subjects included in the curriculum. Geospatial technologies are fundamental elements of a system that can support spatial thinking across the school curriculum, regardless of grade level. GIS for example, has the capacity to map (and model) spatial data, to visualize the data in multiple ways, and to perform a wide range of spatial analyses. Remote sensing, on the other hand, has immense potential to record details about any surface on the Earth at all spatial scales, allowing the monitoring of processes that change constantly in the natural and anthropogenic environment.

Given that the power and utility of geospatial science and technology is being realized fairly slowly in educational systems around the world, maximizing the investment in geospatial technology education requires a clear vision of educational goals and well-developed plans for achieving them. But, in many cases, the rapid flux of technology into schools is running ahead of the educational vision, planning, and training that is necessary to put any technology to proper use.

Can the implementation of a geospatial technologies education program measurably enhance science education and student interest in science and technology? What would be the academic outcomes of such a program? Can these outcomes be measured? These questions may be addressed for projects designed and implemented in the K-12 classroom on the basis of collection of information about the characteristics, activities, and outcomes of each project. The availability and sharing of such information allows not only the estimation of a project's impact, but also facilitates its replication and dissemination.

This paper outlines the vision and impact of SATELLITES, a well-documented program which has provided both a K-12 teacher professional development experience and a STEM education experience for K-12 students. In the following sections the organization and activities of the program will be described. Its results and impact will be highlighted to illustrate the potential benefits of its application to other educational system in other countries, where geospatial technology may not have yet been introduced to the classroom curriculum.

SATELLITES PROGRAM - AN OVERVIEW

The SATELLITES (Students and Teachers Exploring Local Landscapes to Interpret the Earth from Space) program was developed to introduce basic concepts of Earth System Science and Physical Geography to inservice teachers and K-12 students, through the introduction and application of geospatial technology (Hedley et al., 2008). Elementary, middle and secondary level educators attend a one-week summer institute, where they receive training in Earth system science content, spatial thinking concepts, and geospatial technologies. Then, in the following fall, teachers engage their students in inquiry-based research projects using the content and technologies applied during an organized field campaign.

One of the keys to the program is the field campaign, which is supported by geospatial scientists through the GLOBE program. SATELLITES colleagues have been providing teachers with professional development workshops since 1999. Funding and related support for SATELLITES has come from NASA, the US Geological Survey (USGS), the Ohio Board of Regents, the Ohio Space Grant Consortium, and AmericaView. Outreach for the program is achieved through presentations at teachers' conferences or related science education conferences, through publications, by word of mouth between teachers, and via the internet (Point of contact: Dr. Kevin Czajkowski).

The summer institutes provide teachers with high quality professional development that includes exciting and engaging lessons, activities, and materials which are tied to state and national education standards. But the ultimate goal of the program is to increase students' interest and involvement in STEM, thus the summer institute is hosted by scientists that are experts in various disciplines including ecology, urban planning, natural resource management, geomorphology, meteorology, climatology, and related subjects. During each

THE REPORT OF THE CARD AND AND AND AND AND AND AND AND AND AN		
	Green	Forest Vegetation
	Yellow	Grass Area
A A A	Pink	Medium Density Development
A PAN	Red	High Density Development
	Blue	Water

Figure 2. Teachers participating in the SATELLITES training during the summer institutes use MultiSpec, a free, user-friendly software package to analyze Landsat multispectral images. They become familiar with unsupervised classification and use their maps to detect land cover changes around their schools. Polygons drawn using Google Earth showing various land use types around a school in Morgantown, WV.

institute teachers become familiar with remote sensing, GIS, and GPS, and emphasis is put on concepts and technologies that will be integrated in the classrooms during the school year. A guiding focus is the urban heat island effect, and how land use and land cover influence local climate (**Figure 2**).

After being introduced to concepts of location and mapping of the local landscape, which form an introduction to the integration of GPS and GIS, teachers are introduced to the urban heat island effect (Nichol, 2009; Oke, 1973, 2006; US EPA, 2012), a common phenomenon in developed areas whereby they are warmer than surrounding relatively natural areas, particularly at night when much of the urban heat is released. By using a Landsat scene that has been processed to provide surface temperatures (**Figure 3**) students can compare and contrast the temperatures of various surface types associated with concentrated (urban and suburban) development. Developed areas, characterized by asphalt, concrete, metal, and other heat-absorbing materials, tend to raise the local surface and air temperature. Thus, highly developed land cover types can be compared against relatively natural land cover types, such as forests, shrub land, and grassland. These comparisons demonstrate how human development influences local climate.

One main goal of the institutes is to prepare teachers to stimulate creativity in their students, so that students are motivated to use their measurements in an interesting and powerful way. This way SATELLITES may make a difference in the sense that it improves students' ability to generate original, useful, and relevant ideas, increasing their interest in science. Teaching for creativity can, and should, happen in the course of normal education; it doesn't necessarily need special time set aside (Fryer, 2003). But, as Torrance and Myers (1970) have argued, promoting creativity in education demands a skilled and well-prepared teacher, a teacher that understands the creativity underlying the scientific method. Thus, during the institute, the SATELLITES instructors model appropriate inquiry-based techniques for the attending teachers; the teachers thus become students during the institutes and have opportunities to practice inquiry-based pedagogy before using it in the classroom. Teachers are guided to formulate specific questions for the research topics they choose, collect their own data and/or data from the GLOBE web site, use satellite data (Landsat images) or images from Google Earth to support their inquiry. They then refine their questions while working with the data, and ultimately analyze their data using graphs and statistics, and draw their conclusions. Following their training they are better prepared to exercise the scientific method and guide student-based research, as well as acting as facilitators in the inquiry-based learning that is to follow in their classrooms.

Once teachers complete the institute, they have to engage their students in inquiry-based projects in the following school year. One way to do this is through the students' participation in annual GLOBE SATELLITES field campaigns that give them the opportunity to perform genuine scientific inquiry, including collecting, analyzing, and reporting their results through a coordinated, organized, and supported field campaigns. The field campaigns are based on environmental observations, such as local surface temperature measurements of various common land use – land cover types, that are taken using specific GLOBE protocols.



In situ Asphalt - 31.5 In situ Forest Floor - 28.6 (not shown)

Landsat Asphalt - 20.5 (Landsat Forest Floor - 18.2 not shown)

Figure 3. Landsat images from the respective school areas are processed and Land Surface Temperature is derived by the scientists who support SATELLITES. The thematic maps are then provided to the teachers, who, together with their students, compare their in situ data to the satellite data. These comparisons provide important feedback for the approach of the Urban Heat Island effect and introduce students to the principles of remote sensing and the complementarity of the technique with traditional measuring methods.

The Global Learning and Observations to Benefit the Environment (GLOBE) program is a worldwide, hands-on, primary and secondary school-based science education program. Since 1995, when the Program began, 120 countries have participated in GLOBE activities. The program's observations are taken from the atmosphere (temperature, humidity, precipitation, clouds, aerosols, water vapor, surface ozone, etc), the hydrosphere (water transparency, water temperature, dissolved oxygen, salinity, pH, macro invertebrates, etc), the biosphere (land cover, plant phenology, etc) and the pedosphere (soil characterization, soil temperature, soil particle density, soil pH, soil fertility, etc). Each observation occurs within the context of a specific protocol, allowing confident use of the data via the GLOBE web site.

Field campaigns are important aspects of several GLOBE Investigations. Field campaigns are annual or semi-annual events whereby students collect and use their data to address an Earth system science question identified by the scientist. In the past, GLOBE field campaigns have explored hummingbird migration timing, phenology of trees, shrubs, and flowers, and, in the context of SATELLITES, the surface temperatures of common land use - land cover types located near the participating schools. These field campaigns provide an organized, coordinated framework for interaction between students, teaches, and scientists. Not only do they provide a sense of community and an effective way to grow participation in GLOBE via coordinated, supported data collection, they offer an opportunity for students, teachers, schools, and countries to participate in a much larger organized effort to gather, organize, explore, analyze, and share a coherent set of identical data that shows how the Earth is changing, this opens up numerous opportunities for collaboration between teachers, their students, and scientists, and allows powerful and interesting comparisons of their findings. SATELLITES is one of GLOBE's Field Campaigns.

During the SATELLITES field campaign that begins in January and ends in March, teacher support is constantly provided by the project faculty. Students are provided with connections to participating GLOBE scientists and receive guidance on inquiry projects through videoconferencing, webcasts and classroom visits (Czajkowski et al., 2006). The students follow the protocols taught to teachers during the institutes. They then follow through with their research, exploring and analyzing the data and reporting their results as posters and/or video presentations. These posters and presentations are presented at the SATELLITES conference which is held every year in Ohio. Projects are entered in a competition and awards are given to the highest rated projects. During the conference students and their teachers have the opportunity to interact with the scientists and learn more about geospatial technologies and their potential applications.

The 2012 SATELLITES Student Conference was held at Penta Career Center in Perrysburg, Ohio in April. Forty-five student projects were presented by students, and the quality of their work impressed the scientists. In addition to the annual conference, many SATELLITES students have participated in various STEM education related activities. In February 2012, the President of the US hosted the second White House Science Fair, celebrating the student winners of a broad range of STEM competitions from across the country. At the fair, the President viewed exhibits of student work, and made his remarks to an audience of students, science educators, and business leaders about the importance of STEM education to the country's future. Two groups of SATELLITES students participated in the Fair. The first group was from Michigan, and represented O.W. Holmes Elementary-Middle School and Paul Robeson, Malcolm X Academy. The second group was from Huntington High School in Huntington, West Virginia.

The same year, several students from SATELLITES also presented at the 16th GLOBE Annual Meeting in Minneapolis, Minnesota, that was held in July 2012. Those students were from Detroit Public Schools in Michigan, and from Akron City Schools in Ohio.

In 2018, the Urban Heat Island / Surface Temperature GLOBE campaign (as is its current name) took place in October, December and March in an effort to identify seasonal differences. It was very successful, as there were thousands of observations from hundreds of schools from all over the world. The students' data was overlaid on the MODIS sensor data and comparisons were made (**Figure 4**).

As for the SATELLITES Institute, it continues to this point to attract significant numbers of teachers and students in the US. For 2017 in specific, there were 17 teachers that participated in the summer Institute and underwent the professional development session, who in turn involved about 1,000 students. Elementary, middle and high school. Numbers of teachers and students involved for 2018 are to be reported out soon.



Figure 4. On the image for March 26, 2018, the student data is overlaid with surface temperature derived from the MODIS sensor.

IMPACT OF THE PROGRAM

Significant time, effort and other resources have gone into the development and implementation of the SATELLITES program. At each phase of its application, the project team may reflect on the activities that have been performed and evaluate its success as well as the possible need for course corrections. Monitoring how students evolve after their participation in the program provides useful information for that purpose.

Permission has been granted to use a copyrighted spatial abilities test published by AAG (American Association of Geographers) and the author Jongwon Lee, for the evaluation of the students' Spatial Skills. A spatial aptitude or abilities test measures the ability to manipulate shapes in two dimensions or to visualize three-dimensional objects presented as two-dimensional pictures. These tests often involve the visual assembly and the disassembly of objects that have been rotated or which are viewed from different angles or objects that have different markings on their surfaces. The specific test was chosen over other spatial skills tests because it was more appropriate to the spatial skills incorporated in the SATELLITES program.

An effort to identify the impact that the program has on the spatial skills of the students was made processing the results from the tests taken by students between 2011 and 2014.

The test was administered three times during the schools year: students took a pre-test before the program described started, one post-test test (referred to as "Post-test 1") after the surface temperature field campaign ended, and a second Post-test (referred to as "Post-test 2") after they worked on their research project. The data was analyzed and compared and focus was put on the increase in correct answers on post-tests compared to pre-tests. The results were grouped into two categories: high school students and elementary school students. On average, the test-takers have a 4 points score increase at Post-test 1 and 5 points score increase at Post-test 2. The numbers of the students that participated in the research between 2011 and 2014 can be found in Table 2. Also, for clarity purposes, a brief description of the test questions is provided in Appendix 1.

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Table 1. Average Final Score Grown	i Comparing to rife-test.		
Average Final Score	Pre-test	Post-test 1	Post-test 2
2011 High School Students	8	10	10
2012 High School Students	5	5	7
2013 High School Students	7	9	9
2014 High School Students	5	8	6

Table 1. Average Final Score Growth Comparing to Pre-test.

Table 2. Average Final Score of each group for Pre-test, Post-test 1 and Post-test 2.					
Average Score Growth	Growth After Post1	Growth After Post2	Number of students		
2011 High School Students	2	2	39		
2012 High School Students	0	1	7		
2013 High School Students	7	10	82		
2014 High School Students	2	1	12		

Score Growth Comparing to Pre-test (2011)

According to the Average Score Growth by Question for years from 2011 to 2014, the average scores of both post-tests of most questions were higher than those of the Pre-test. It can also be inferred from the graphs (**Figures 4-9**) that 2013 had a more significant positive growth than 2011 and 2014 in terms of both the questions answered correctly and the score growth for each question. The positive growth of the average score by question for 2012 is not very distinct. It is also worth noting that the growth after Post-test 1 is greater than the additional growth after Post-test 2. As shown in the Table and Graph of Average Final Score Growth from 2011 to 2014 (**Table 2**), as well as the Table of Graph of Average Final Score from 2011 to 2014, 2013 (**Table 3**) had the most significant growth in the final score. This result matches that of the previous analysis.

Question Number (Participants n=39) Figure 5. Score Growth of High School Students Compared to Pre-test in 2011 by question.



Growth (Participants n=7)

Figure 6. Score Growth of High School Students Comparing to Pre-test in 2012 by question.



Score Difference Comparing to Pre-test (2013)

Question Number (Participants n=82) **Figure 7.** Score Growth of High School Students Comparing to Pre-test in 2013 by question.



Question Number (Participants n=12) Figure 8. Score Growth of High School Students Comparing to Pre-test in 2014 by question.



Average Score Differences Comparing to

Figure 9. Average Final Score Growth Comparing to Pre-test of High School Students from 2008 (earlier data) to 2014. For 2008, there were 45 high school and 42 elementary school students that took the test, while for 2009, 29 elementary school students.



Figure 10. Average Score Growth by Question after Post-test 1 (a) and Post -test 2 (b) by Question.

In general, high school students in 2013 experienced the greatest improvements to their spatial skills. Another interesting element was to identify which of the spatial skill questions scores had the more significant growth for students. The top three were questions 9, 15, 16 after Post-test 1 and 8, 15, 16 after Post-test 2.

Questions 15 and 16 were the ones that presented the higher improvement in students' scores. Students who were not familiar with geography science may have had a hard time understanding the concepts and objects referred to in questions 13 and 14, therefore resulting in lower score growth when compared to questions 15 and 16. Questions 9, 10, 11 and 12 all showed relatively high growth, indicating some improvement in recognizing the relationships between shapes. On the other hand, questions 1, 2 and 3 showed the lowest growth after both Post-test 1 and Post-test 2. These questions not only required test-takers to follow directions, but also to understand the directions; any misunderstanding of the written directions could lead to different answers. Question 3 did not involve potentially confusing directions, as was the case in questions 1 and 2, however, test-takers who were not very familiar with math or function graphs seem to have found question 1 challenging.

The organizers identified some potential sources of error for the test-taking process which were: 1.The students' physical condition on the day of test. 2. Possible test anxiety that occurs when students are too nervous to think and recall learned material during the exam. 2. Students' interest and passion for the program after the training and the following data collecting. 3. Students' understanding of the questions and directions (in particular, younger students who may have had a harder time to comprehend the content of the questions). 4. Students' appropriate preparation for the test. 5. The fact that different teachers participate in this process each year. And they are the ones preparing the students.

The pre- and post- tests provide quantitative evidence for the effect that the SATELLITES program has been providing a powerful learning environment for students. At the same time, the program goes beyond what is taught in the classroom and enables students to apply the knowledge they are learning in their classes to more specific questions. SATELLITES creates meaningful student-teacher interactions, particularly when teachers work with their students for their research projects. At that point, students become excited and engaged, build their confidence and realize the relevance between the world and their education.

DISCUSSION AND FUTURE WORK

The geospatial technology field is rapidly evolving, providing many opportunities in a wide range of disciplines and occupations. This growth is both exciting and challenging. Data and tools for geospatial processing and analysis are extremely important for the monitoring and management of natural resources at all scales, from local to global. Reports emerging from several research bodies address the need for K-12 schools to teach spatial thinking skills that are facilitated and strengthened by the use of geospatial technologies. At the same time, there is evidence that the application of geospatial technologies can be a powerful tool for the enhancement of teaching and learning, promoting interest in science in a range of thematic areas. However, despite all of its inherent potential for integration into existing curricula, there remains a very high percentage of teachers that are still not using geospatial technology in their classroom instruction. The barriers to continued proliferation of GIS in K-12 education tie most strongly to teacher training in pedagogy, curriculum, and technical skills.

SATELLITES is a program that has been designed to enhance the use of geospatial technologies in science teaching practices. Taking advantage of the excitement of its participants and the power of geospatial technologies for teaching, it has been shown to promote Earth system science education. SATELLITES has been operational for 20 years, and its impact demonstrates that 1.) it matches K-12 needs and capabilities in science education; 2.) it has realistic and meaningful goals for its operation; and 3.) it has the capability to use limited and affordable resources wisely and very effectively to promote its purposes. Furthermore, the systematic approach to the project implementation process has documented that SATELLITES is transferable to a much broader audience, not only in the US, but around the world. There is a continuous process for the identification of opportunities to include teachers all over the country and in other countries of the world in this effort.

Engaging teachers to participate in SATELLITES is itself a challenge, as teachers are typically busy and often do not have extra time to devote to programs. However, the program's reputation has helped in overcoming the challenges and attracting considerable numbers of teachers on a yearly basis. SATELLITES provides a well-structured professional development that builds a community, integrates diverse content and pedagogical expertise, provides continuous support and mentoring and is of sufficient duration to bring change. It is a program that has impact on the teachers and their students. Teachers bring geospatial technology in their classroom and see the spatial abilities and the sense of space of their students change. Spatial skills are vital for understanding the world. In the framework of the Program, teachers and students are using geospatial technologies to investigate the whys, engage in problem solving at the local and the global (through collaborations) level and broaden their critical thinking and science skills. It is also very interesting to consider that these technologies can play a very important role in the education for a global citizenship.

The people involved in SATELLITES are always looking for opportunities is to identify and develop effective partnerships to reach interested schools (teachers and students) and invest in options that may actually work, such as leveraging scientific equipment for use in field campaigns. A basic rule is keeping in mind that existing 'best practices' should be documented and used, thus saving time, effort and resources, without falling into the temptation of creating something new and untested for its own sake. The creation and establishment of successful new collaborations, with the provision of feedback and continued coaching will further promote the program's vision to encourage and strengthen innovative teaching and research in science education.

Disclosure statement

No potential conflict of interest was reported by the authors.

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APPENDIX 1

- **Question 1:** Follow written directions based on a provided street map, then determine the final destination. North arrow is pointed toward the bottom of the page instead of the top.
- **Question 2:** Follow written directions based on a provided street map, then determine the final destination. North arrow is pointed toward the bottom of the page instead of the top.
- **Question 3:** Match the precipitation pattern on a map with one of five graphs.
- **Question 4:** Use four maps and determine the optimal location for a flood management facility based on several conditions, elevation, land cover, nearness to electronic line, etc.
- **Question 5:** Provided a terrain map and asked test-taker to match one of five slope profiles to a given point of view on the map, i.e. view shed.
- **Question 6:** Provided a map and asked test-taker to determine which of six maps had the strongest positive correlation with the given map.
- **Question 7:** Provided two maps and asked test-taker to determine which one of four line graphs best depicted the correlation between the two given maps. Corn and hog production
- **Question 8:** Provided a terrain map and asked what the terrain would look like from a given point marked by an arrow.
- **Question 9:** Determine the relationship between two similar shapes.
- **Question 10:** Understand the relationship between two irregular shapes.
- Question 11: Find the shape that best matched two given conditions.
- Question 12: Find the shape that best matched three given conditions.
- **Question 13:** Choose the best method to represent the location of weather stations.
- **Question 14:** Choose the best method to represent river channels and basins.
- **Question 15:** Choose the best method to represent bus routes.
- **Question 16:** Choose the best method to represent the places that can be reached by a fire engine within 5 minutes.

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