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Persistent Teaching Practices After Geospatial Technology Professional Development

Abstract

This case study described teachers with varying technology skills who were implementing the use of geospatial technology (GST) within project-based instruction (PBI) at varying grade levels and contexts 1 to 2 years following professional development. The sample consisted of 10 fifth- to ninth-grade teachers. Data sources included artifacts, observations, interviews, and a GST performance assessment and were analyzed using a constant comparative approach. Teachers' teaching actions, beliefs, context, and technology skills were categorized. Results indicated that all of the teachers had high beliefs, but their context and level of technology skills strongly influenced their teaching actions. Two types of teachers persisting in practices from professional development were identified: innovators and adapters. Persistence of practice and implementation of the integration of GST within PBI must continue after professional development ends, or the sustainability of the positive results experienced during the professional development will not persist.

A common goal of professional development (PD) is to improve teachers' skills, understanding, and pedagogical practices in order to impact student learning (Wallace, 2009; Yoon, Duncan, Lee, Scarloss, & Shapley, 2007). However, no simple input-output model exists; there are many mediating factors between what teachers experience during PD and how it is translated into student learning experiences in the classroom (Desimone, 2009; Guskey, 2002; Whitworth & Chiu, 2015).

Often, evaluation efforts of technology education PD document implementation of pedagogical practices during the life of the program, but little is known about whether these practices persist once the programmatic supports end (Baker et al., 2015; Lawless & Pellegrino, 2007). Recently, a proposed geospatial technology (GST) and learning research agenda suggested the identification of the technological, pedagogical, and content knowledge required for teachers to implement and use GST as a priority for the field moving forward (Baker et al., 2015).

The current study begins to address this priority. The purpose of this research was to determine what pedagogy persisted following a PD institute with project-based instruction integrating GST and what factors promoted or hindered sustained implementation of these practices.

Project Based Instruction

Project based instruction (PBI) is a teaching method designed to promote students' development of 21st-century competencies (critical thinking, communication, collaboration, and creativity; Partnership for 21st Century Learning, 2015) through a collaborative, structured inquiry of an engaging and complex question, problem, or challenge (Krajcik, Blumenfeld, Marx, & Soloway, 1994; Larmer, Ross, & Mergendoller, 2009). PBI also requires engagement in the practices of science, which translates into a deeper learning experience (National Research Council [NRC], 2012). Many GST-integrated PD programs have promoted the use of PBI integrated with GST (e.g., Bodzin, Anastsio, & Kulo, 2014; Kolvoord, Charles, & Purcell, 2014).

Professional Development for Geospatial Technologies

GST is a powerful tool to support spatial thinking, scientific research, and real-world problem solving (NRC, 2006; Sinton & Lund, 2007). Teachers who utilize GST within student-centered practices in their classrooms provide opportunities for students to engage in data collection, analysis, and argumentation based on evidence (MaKinster & Trautmann, 2014).

PD is a critical component in the overall success of teachers' development of practices that will lead to effective implementation of science and technology in an authentic environment. Developing science content understanding, the intellectual capabilities of their students, and specialized pedagogical knowledge requires specialized PD focusing on the core ideas in the discipline and modeling of how teachers should present the material to their students (NRC, 2007).

Koehler and Mishra (2005) stressed the need for authentic, project-based PD activities to help teachers develop this knowledge of how to teach content with technology effectively. To teach effectively with GST, teachers must build their knowledge, skills, and practices before they can implement lessons with students and realize instructional changes that ultimately lead to student learning gains (Desimone, 2009; Guskey, 2000). In addition, PD must help teachers integrate knowledge of GST into their existing schema (Coulter, 2014; Kolvoord et al., 2014).

As technology has been infused into most schools, and with greater accessibility of GST tools such as ArcGIS online and Google Earth, teachers can now focus on more sophisticated, student-centered technologies. In order to provide teachers with effective PD around GST and PBI, facilitators should immerse teachers in a real-life problem which involves the examination of spatial data (Borko, 2004; Loucks-Horsley, Love, Stiles, Mundry, & Hewson, 2003). As teachers grapple with spatial data to resolve a problem, they are able to experience many of the same issues and struggles students encounter.

By becoming a learner of the content via immersion in inquiry, teachers broaden their own understanding and knowledge of the content they are addressing with their students (McAuliffe & Lockwood, 2014; Moore, Haviland, Whitmer, & Brady, 2014). Experiences should focus on teaching with GST and on learning more advanced tools as they become necessary for the exploration at hand (Barnett et al., 2014; McClurg & Buss, 2007).

Providing lessons and datasets that can be used immediately in classrooms supports implementation, but it is important to allow for some adaptation of the teaching materials to meet teachers' needs (Kolvoord et al., 2014; Moore et al., 2014; Stylinkski &

Doty, 2014). It is also imperative that teachers understand the theory behind the lesson design, so when changes are made, critical components are maintained (Singer, Marx, & Krajcik, 2000).

Implementation of Geospatial Technologies in the Classroom

When teachers begin implementing GST-integrated PBI lessons they face barriers, such as finding time to implement projects, pressures of high-stakes testing, technology access, and computer glitches (Baker & Kerski, 2014; Barnett et al., 2014). Kerski (2003) said that teachers who expressed an interest in teaching with GST did not actually use it until 1 to 3 years after they received the software. Teachers require adequate support, not only in the form of technology infrastructure, administrative permission, and time to allow students to engage in authentic inquiries, but also from a community of practice and educational mentors (Blank, Crews, & Knuth, 2014; Rubino-Hare et al., 2013; McClurg & Buss, 2007).

Long-term PD allowing time for practice, reflection, and discussion with others increases teacher implementation (Baker & Kerski, 2014; Desimone, 2009; Loucks-Horsley et al., 2003). When teachers see the engagement and learning gains from their students, they receive positive reinforcement and gain confidence to implement further (Guskey, 2002; Yarnall, Vahey, & Swan, 2014). Teachers who are comfortable with student-centered approaches such as PBI and those who are willing to learn alongside their students seem to be drawn to GST as a teaching tool and have had success in implementing (Baker & Kerski, 2014; Baylor & Ritchie, 2002; Coulter, 2014).

Charles and Kolvoord (2003) described four stages through which teachers progress as they begin to teach with GST: entry, adopt, adapt, and innovate. Kolvoord et al. (2014) presented illustrative cases for the stages. During the *entry* stage, teachers are able to use GST within PD. The next stage sees teachers *adopt* and teach lessons that use GST to teach content as written, without modification. Teachers who modify lessons to meet instructional objectives and student needs are in the *adapt* stage. When teachers begin developing their own original activities, they have reached the *innovate* stage. The ultimate goal of GST PD should be to move teachers along this continuum.

The Power of Data Projects

The Power of Data projects sought to increase science, technology, and 21st-century skills through immersive PD experiences with PBI, by requiring teachers to propose solutions to authentic problems through spatial data collection and analysis utilizing GST (Rubino-Hare et al., 2013). Following the PD, teachers were expected to implement similar GST-integrated PBI units in their classrooms. The PD team included geology faculty members, science teacher professional developers, GST experts, and science education researchers.

PD institutes focused on teaching Earth science with GST. The premise for the institutes was that modeling and practicing research-based pedagogical methods through an immersion program focusing on real-life problems would improve participant science instruction (Loucks-Horsley et al., 2003; Parker, Carlson, & Na'im, 2007). The expectation was that instructional modeling would elicit a deeper level of understanding of how to integrate GST into content in a PBI context.

Teacher teams who demonstrated the ability to implement PBI and integrate technology in their classrooms were recruited to increase the likelihood of success during implementation (as in Blank et al., 2014; Coulter, 2014; Kerski, 2003). During the PD institutes, spatial analysis with the goal of answering a question and presentation of projects using spatial data as evidence to communicate claims was emphasized (as recommended by Bodzin, Anastasio, & Kulo, 2014; Coulter, 2014; Zalles & Pallant, 2014).

Teachers experienced an Earth science unit utilizing commercially available GST lessons (as in Johnson & Schmidts, 2005; Palmer, Palmer, & Malone, 2008; Palmer, Palmer, Malone, & Voigt, 2008) organized into a PBI unit designed to build conceptual understanding (as recommended in Larmer et al., 2009; Schwartz et al., 1999). Teachers were then asked to implement the lesson with students, encouraging modifications for local relevancy (as in Coulter, 2014; Kolvoord, et al., 2014; Penuel, Fishman, Yamaguchi, & Gallagher, 2007; Stylinski & Doty, 2014). The premise was that implementing the lessons with students would enable teachers to see the benefits for student learning and encourage continued use (Baker & Kerski, 2014; Guskey, 2002; McAuliffe & Lockwood, 2014; Trautmann & MaKinster, 2014; Yarnall et al., 2014).

Although the PD content was similar, two models of PD were enacted, one that occurred over an intensive, 2-week summer institute and one that was implemented on weekends throughout the academic year (Claesgens et al., 2013; Rubino-Hare et al., 2013). After initial PD, both groups were invited to participate in an advanced 1-week summer institute to learn more about the theories behind the lesson design and to develop their own PBI units.

Because technology was added to the already high demands of new student-centered and PBI pedagogies, barriers to implementation were anticipated and addressed in the design of the PD. These interventions included developing teachers' content, pedagogical, and technical knowledge, requiring support from administrators and information technology (IT) specialists to ensure technology access, and providing classroom resources, including software, books, and data collection devices (as recommended by Kerski, 2003; Mumtaz, 2000; Tamim et al., 2011).

In previous studies of the Power of Data projects, teacher skills, knowledge, school support, and student learning were measured pre and post participation in order to determine overall effectiveness of the PD and the impact of the PD format on student learning (Claesgens et al., 2013; Rubino-Hare et al., 2013). Results indicated that when there was a high level of implementation of PBI integrating GST, teachers and their students improved their performance on a number of factors regardless of the PD format.

Purpose

A common assumption is that in order for student learning gains to occur following teachers' participation in PD, changes to pedagogical practices must persist beyond the PD (Desimone, 2009; Guskey, 2002). Yet, ability to sustain practices in teacher participants is a challenge for high-quality PD programs (Lawless & Pellegrino, 2007).

Many variables come into play that affect implementation, sustainability, and ultimately, student learning (Lawless & Pellegrino, 2007; Whitworth & Chiu, 2015). Lawless and Pellegrino urged for these variables to be systematically investigated and the need identified to determine if pedagogical change persisted after PD. Furthermore, identification of the support structures needed to maintain long-term pedagogical change was suggested (Lawless & Pellegrino, 2007).

The challenge is to determine what critical factors in high-quality PD programs support persistence of pedagogical practices. Therefore, based on findings from the previous study (Claesgens et al., 2013), the research questions guiding the current study were as follows:

1. What pedagogical practices did teachers sustain following the PD experiences?
2. What contexts were present in schools that supported or limited the use of GST as a teaching and learning tool?
3. What characterized teachers who sustained practices?

The study presented here followed teachers 1 to 2 years post-PD to construct a more complete picture of the aspects that affected the path from professional learning experiences to the classroom.

Methods

This study employed a qualitative case study approach (Yin, 2014) to describe the experiences and perceptions of teachers who continued to implement their learning in the first and second years after PD ended. When a lack of in-depth understandings of a phenomenon exists, case study designs are appropriate (Creswell, 2009). The unit of analysis for the study was the teacher within the classroom. A variety of data, including artifacts, classroom observations, interviews, and survey results, were collected.

Context

The Power of Data PD was offered in two formats: one through an intensive 2-week summer institute and the other via monthly or bimonthly meetings throughout the academic year. Both formats immersed teachers as learners in a GST-integrated collaborative PBI unit, with the goal of responding to a driving question related to an Earth science concept (weather and climate and mass wasting, respectively).

Global/regional investigations and inquiry-based science labs were followed by an application of the science concept in a more local context to propose mitigation solutions. For example, teachers analyzed world and regional data to understand the differences between weather and climate (e.g., Power of Data Unit on Weather and Climate; see Appendix A). Armed with a greater conceptual understanding of how climate change can result in extreme weather and how extreme weather might affect the Earth system, they studied a local watershed and stream system (e.g., Power of Data Unit on Climate Change Site Mitigation; see Appendix B). The final products presented were short- and long-term recommendations to a fictional community planning commission for site modification along the stream system.

Teachers were encouraged to replicate this process in their classrooms. They received lessons and datasets that could be implemented immediately as written or adapted as necessary. They were then encouraged to develop and teach an authentic PBI lesson for their context that required students to collect and analyze local data, integrate non-GST hands-on science investigations, and present solutions. During the PD, participants spent time planning lessons and future implementation. As they taught the lessons they received peer feedback through both face-to-face and online discussions to encourage a professional learning community.

Initial analysis of data from classroom observations, teachers' self-reports, and students' work from lessons indicated three levels of initial implementation following PD: high implementers, mechanical implementers, and nonimplementers (Rubino-Hare, et al., 2013). High implementers were those who used GST, assigned students authentic projects that emphasized claims and evidence, and often required students to present project findings to stakeholders. In comparison to the high implementers, mechanical implementers were more comfortable implementing step-by-step lessons from a GST text. Lessons and student assignments tightly followed the curriculum materials presented in the PD, though occasionally teachers adapted materials and students collected data in the field. The third group, non-implementers, did not implement GST within lessons, and students did not use the software in any capacity.

Many of the teachers participated in an advanced 1-week summer institute to learn more about the theories behind the lesson design, learn and practice targeted GST skills, and develop and prepare data and base maps for their own GST-integrated PBI units (e.g., Advanced Institute Unit on Grand Canyon Ecology and Advanced Institute Unit on Local Water Resource Analysis; see Appendixes C and D). During the advanced institute, teachers received individualized support from the pedagogical, technical, and subject matter experts.

Participants

One year after completing the final PD project, all former Power of Data participants who were still teaching (n = 60) were contacted and asked to complete an online survey to identify what aspects of the PD they were still implementing in their classrooms. A total of 47 participants completed this follow-up survey, representing a total response rate of 78%. Ten of the teachers who completed this survey (21% of survey respondents) were purposefully selected for this study based on two criteria: level of initial implementation and continued use of GST in the classroom. The 10 teachers selected for this study were previously identified as mechanical or high implementers during the initial PD and reported on the survey that they were continuing to teach with GST. These criteria for selection were used in order to determine if high levels of pedagogical practices continued 1 to 2 years following the PD experience. Descriptive characteristics of the participants are presented in Table 1.

Data Collection

Multiple methods of data were collected to triangulate findings, identify patterns, and develop a rich description of the patterns of implementation and persistence of practice (as in Creswell & Miller, 2000). Data sources included artifacts, classroom observations, semistructured interviews, and GST performance assessments. Because the research focus was on persistence of pedagogical practices, authentic classroom artifacts generated by each teacher were used as data. Face and content validity for the interview protocol and GST performance assessment were established through review by a team of geospatial educators. Modifications were made to the interview protocol and GST performance assessment as suggested by the team. Validity of the Inside the Classroom Observation and Analytic Protocol has been established previously (Horizon Research, Inc., 2000).

Artifacts. Teachers submitted their lesson plans for GST-integrated, inquiry-based lessons. When applicable, they submitted course syllabi for the courses where GST-integrated lessons or PBI units would be implemented. Teachers also submitted student work samples for GST-integrated lessons or PBI units they implemented. These artifacts provided insight into how teachers utilized GST in their lessons and if or how they designed PBI units for their curriculum.

Table 1
Description of Participants, *n* = 10

Demographic Category	Descriptor	*n* (%)
Grade level	Middle School	3 (30%)
	High School	7 (70%)
School type	Public	7 (70%)
	Charter	3 (30%)
School location	Rural	5 (50%)
	Urban	2 (20%)
	Suburban	3 (30%)
Subject Matter	Science	9 (90%)
	CTE	1 (10%)
Years Post PD	One	6 (60%)
	Two	4 (40%)
Advanced PD	Attended	6 (60%)
	Did not attend	4 (40%)
Initial Implementation Designation	Mechanical	4 (40%)
	High	6 (60%)

Semi-structured interview. The interviews were designed to be completed in 30 minutes and were conducted by researchers external to the PD delivery team to discourage bias and to elicit honest responses from participants (see Appendix E). The goal of the interview was to understand what, if anything, teachers were still using from the PD and why. Teachers were first asked questions about their background with technology integration in general. Other questions were asked to construct an understanding of teachers' school context, and specific questions were asked about what from the PD they were implementing and why. Participants were also asked to identify barriers to implementation and how they might have overcome these obstacles. Finally, teachers were asked about perceived or actual impacts on student learning and attitudes and plans for future instruction. Interviews were tape-recorded and transcribed for analysis.

Classroom observations. Teachers were asked to identify a GST-integrated inquiry-based lesson in order for the researchers to conduct classroom observations. Prior to the lesson teachers were asked to identify the purpose of the lesson, the context of the lesson (days prior and following lesson), and the elements of inquiry that were present in the lesson. Classroom observations were conducted using a modified instrument based on Inside the Classroom Observation and Analytic Protocol (Horizon Research, Inc., 2000). Sections of implementation from the protocol were chosen as a focus (Table 2). Observers were looking for evidence of high-quality teaching, based on the degree of student-centered teaching as opposed to direct instruction, and the degree to which inquiry was valued and encouraged.

Table 2
Domains and Items in Observation Protocol

Implementation
• The instructional strategies were consistent with investigative mathematics/science.
• The teacher appeared confident in his/her ability to teach mathematics/science.
• The teacher's questioning strategies were likely to enhance the development of student conceptual understanding/problem solving (e.g., emphasized higher order questions, appropriately used "wait time," identified prior conceptions and misconceptions).
Mathematics/Science Content
• Students were intellectually engaged with important ideas relevant to the focus of the lesson.
• Appropriate connections were made to other areas of mathematics/science, to other disciplines, and/or to real-world contexts.
Classroom Culture
• The climate of the lesson encouraged students to generate ideas, questions, conjectures, and/or propositions.

GST Performance Assessment. A GST performance assessment was administered pre- and post-PD to teacher participants. This assessment measured participants' abilities to use the ArcGIS software and was developed and used to measure GST skills as part of the original Power of Data projects. Teachers were asked to perform increasingly complex tasks, from opening an existing map document and obtaining information from data tables to creating a map layout that communicates information from the data in a choropleth map.

Data Analysis

A constant comparative analysis (Strauss & Corbin, 1990) was employed to analyze the qualitative data collected and to evaluate the sustained pedagogical practices of teachers. A summary of the alignment between the research questions, data sources, and data analysis is provided in Table 3. Data were analyzed to identify the level of teachers' teaching actions, beliefs about teaching and learning, teaching context, and technology ability. The criteria and categories emerging from the data and describing the levels in each of these areas are described in Appendix F. Further description of the analysis follows.

Table 3
Alignment Between Research Questions, Data Sources, and Data Analysis

Research Question	Data Sources	Data Analysis
What pedagogical practices did teachers sustain following the professional learning experiences?	• Classroom observations • Artifacts • Interview transcripts	• Coded observations and artifacts for how teachers sustained pedagogical practices. • Confirmed coding with interview transcripts.
What contexts were present in schools that supported or limited the use of GST as a teaching and learning tool?	• Interview transcripts • Classroom observations • Artifacts	• Coded interview transcripts for teaching contexts that supported or limited GST use. • Confirmed coding with classroom observations and artifacts.
What characterizes teachers who sustained practices?	• Interview transcripts • GST Performance Assessment • Artifacts	• Coded interview transcripts for beliefs. • Coded GST performance assessment for technological skill using GST. • Confirmed coding with artifacts.

Teaching actions. Implemented pedagogical practices were categorized as teaching actions. The following teaching actions were identified from a review of all the data:

- Opportunities for students to engage in authentic projects.
- Opportunities for students to collect and analyze data.
- Opportunities for students to work with or present findings to local stakeholders and professionals.
- Opportunities for students to use GST to learn content and communicate ideas.

These actions were informed by the PBI literature (Krajcik, Blumenfeld, Marx, & Soloway, 1999). Teachers who used all four of these teaching actions were coded *high* (Appendix F). Those teachers who met three of these criteria were coded *medium*. For example, one medium-action teacher modified a lesson about a hazardous spill from a GST text to provide a local, authentic context, and the students used GST to communicate their ideas. If fewer than three teaching actions were present, the teachers were coded as *low*. Teachers who were coded low were not completely void of student-centered teaching. For example, one low-action teacher attempted to make learning relevant for students by delivering a lecture and providing news articles about current natural disasters, but students followed step-by-step instructions to study old data from a text provided during the PD rather than exploring current data or a relevant local natural disaster. Teachers who used none of the identified teaching actions were coded *none*.

Beliefs and context. Themes emerging from teachers' interview responses about supports or barriers to teaching with GST were examined. Transcriptions of interview data were read individually by three researchers and open coded to classify elements of the data and look for emerging categories or themes. Three researchers reviewed these initial codes. To ensure interrater reliability, similar codes were merged, redundant codes were eliminated, and definitions and codes were developed into the initial codebook. Each interview was then recoded by two researchers, and 100% agreement was reached through discussion. The codes were crosschecked and then revised to form more broad categories.

Patterns in the interview responses formed around (a) beliefs about teaching and student learning and (b) context. Teachers' discussions of beliefs about teaching and learning were coded as beliefs. Teachers' discussions centered around the following six ideas: student-centered approaches, high outcome expectancy for students (Bandura, 1977), the importance of making learning relevant for students, data collection and analysis opportunities for students, engaging community members as stakeholders in student learning, and recognition of GST as a tool for student learning and communication instead of a learning goal in itself.

Following the development of these categories, we further examined transcripts to code teachers as *high, medium*, or *low* in the category. Teachers who described four or more of these beliefs about teaching and learning were coded as high beliefs, teachers who discussed three of these beliefs were coded medium beliefs, and teachers who scored two or fewer of these beliefs were coded low beliefs (Appendix F).

The code context describes the school structure and environment, including the course in which the teacher implemented GST, technology support, and school support. Teachers' discussions of context were coded based on the following: class size, flexibility in subject matter and curricular decisions, access to reliable technology, extended time to work on projects, administrative, IT, and teaching supports (e.g., resources such as texts, lessons, and equipment).

If five or more of these conditions were in place for a teacher, they were categorized as high context (Appendix F). High-context teachers had a great deal of flexibility, time, access to computers, and support to implement projects using GST with students. If a teacher had three or four of these conditions in place, they were coded as medium context. For example one medium-context teacher had larger class sizes and only seven computers, but had a great deal of support from administration and a supportive colleague who helped with projects. Those teachers who had fewer than three of the conditions in place were categorized as low context. One low-context teacher had small class sizes but an administrator who was very focused on reading and mathemathics and did not support the use of technology with students and provided little access to reliable computers.

Technology. To provide insight into teachers' abilities with GST and classroom implementation, teaching actions again were examined and teachers' technology skills were studied to create a better characterization of the teachers. To understand teachers' technological knowledge, teachers' performance on the GST performance assessment was examined . This assessment measured participants' abilities to use ArcGIS software to display layers, obtain information, and communicate variability in data (Appendix F). Teachers who were able to obtain or create data of their choosing, generate maps, and create graphical representations from data to communicate bigger ideas were scored as *high* in technology. *Medium*-level technology teachers could generate maps and create graphical representations from data provided to communicate ideas. Teachers who could create basic maps from provided data and obtain information from data to answer or generate their own questions were coded as *low*.

Results

The purpose of this qualitative case study was to explore the critical factors impacting teachers' persistence with integration of GST within PBI units 1 to 2 years following PD. Ratings for teachers in teaching actions, context and beliefs, and technology are found in Table 4. All teachers had high beliefs at the time of the study, but displayed a range of levels in technology, context, and teaching actions. Further exploration of these findings is presented first, followed by a presentation of two illustrative cases.

Table 4
Teachers and Categories 1 to 2 Years Post PD

Teacher	Teaching Actions	Teaching & Learning Beliefs	Teaching Context	Technology Ability
A	high	high	high	high
B	high	high	high	high
C	high	high	high	high
D	high	high	medium	high
E	high	high	medium	high
F	med	high	low	medium
G	low	high	low	medium
H	low	high	low	low
I	low	high	medium	medium
J	low	high	medium	low

Teaching Actions

Results indicate that all teachers persisted at some level with the pedagogical practices presented during the initial PD. Five of the 10 teachers displayed all four of the teaching actions and were identified as high action. For example, one high-action teacher recognized the value students placed on a stream that runs behind their school. The teacher capitalized on students' concerns about the quality of the water to engage them in an authentic environmental study (e.g., Power of Data Lesson Plan on

Macroinvertebrates, Appendix G). The students collected water quality data such as pH and turbidity. They also captured and cataloged macroinvertebrates at different points in the stream. They mapped and analyzed these data using GST and then used the data as evidence to make claims about stream health.

One teacher used three of the teaching actions, identified as a medium action, and four used two of the teaching actions, identified as low action. The medium-action teacher modified a lesson about a hazardous spill from a GST text to provide a local, authentic context. Since the school was near a nuclear power plant, the teacher invited the fire department to share a story about an aerosol can spill that happened a few years prior, which resulted in the closing of a major interstate for 7 hours. The students used this story to consider emergency response of another potential hazard. They researched the worst-case scenario effects of a possible explosion at the plant, calculated the extent of the hazard area, developed an emergency plan to divert traffic and keep the area safe, and presented and defended their plans to each other. In the future the teacher plans to have students present to the school board and the fire department.

Low implementers generally did not include authentic experiences. For example, one low action teacher attempted to make learning relevant for students by delivering a lecture and providing news articles about current hazardous weather events, but students studied data about an older weather event from a text provided during the PD rather than current weather data, which would have resulted in a more authentic project (e.g., Power of Data Lesson Plan on Weather and Climate; Appendix H).

Context

Context is an essential element of teachers' ability to implement new technology and pedagogical practices (Cox, 2008). Three teachers scored high in context, four scored medium, and three scored low. Based on the experiences of all teachers studied, four critical contextual factors were identified as especially important for persistence of practice: subject matter alignment, curricular flexibility, assessment, and support.

All teachers in this study taught science or technology classes. Earth, environmental, and life sciences seemed particularly suited to conducting fieldwork, data collection, and the analysis GST affords, possibly because the nature of these disciplines generally requires examination of spatial data to identify patterns, and relies on a systems perspective for their theories. Teachers in these content areas appeared to be able easily to integrate pedagogy and technology into the curriculum being taught. For example, an Earth science teacher described how GST was used to gather and explore data students collected after a nearby fire and how the students used these data to make claims about erosion:

> Earth science, it's real easy to use the GIS....[It] really helps with the evidence part, and not just, "Here's a map with everything on it." It's better for [students] to explore [a site] and find [data] themselves.... I think it's beneficial because you can visualize and you can sort the data. It's something useful in looking for patterns, and that's really something I wanted my students to do, like, "Do they see a pattern in the data they collected?" ...We can just talk about fires or just talk about erosion, or we can talk about a real example. (Teacher D)

This teacher was able to connect the subject matter to the technology easily; thus, she was able to implement the technology within her classroom.

Second, curricular flexibility, or the ability to choose the pedagogical strategies and sequencing of lessons necessary to arrive at learning goals, also affects implementation. For example, Teacher H felt constricted by curriculum:

> In 6-8, we're departmentalized, so the sixth graders get their reading time using a scripted reading program that the rest of the school is using. So that's very restrictive....Time is prescribed, the teacher's manual tells the teacher exactly what to say and what materials to have ready at every point in the lesson. No flexibility at all. I would say that at this point in time, the reading program overrides the curriculum. (Teacher H)

The lack of flexibility in the curriculum and inability of Teacher H to change this prescribed curriculum led to reduced implementation. It also reduced the teacher’s ability to choose the best pedagogical approach to utilize in lessons.

In addition to a supportive context, teachers who understand how particular technologies and pedagogies impact student learning are able to understand more easily how to meet educational objectives using these technologies (Cox, 2008). In this study, some teachers struggled to see how teaching their particular content with GST would meet student learning objectives. One example of this was Teacher G: “I have to write lesson plans and I have to [identify] what standard I am teaching to. Would you please show me standards for the state of [omitted] for GIS?” This teacher did not see GST as a tool for helping students learn the content. He was still thinking about the technology as the learning goal.

Given there were no explicit state standards for GST and his lesson plans were checked by his administration, Teacher G had difficulty identifying standards and was concerned about implementing the project in his classroom. In contrast, Teacher E recognized the pressure of high-stakes testing, but was allowed flexibility in his teaching approach, which empowered him to make the best pedagogical choices for his students:

> We do have a...district test for every class. And then, in my [Advanced Placement] AP class I have...that AP exam. But...there’s nobody telling me the road I need to take to get there. So it’s kind of like, “This is where we want you to be successful in these things, but we’re very open to...how you get students there.” (Teacher E)

This teacher may have had a more developed sense of how the GST was an appropriate tool to help his students reach their learning objectives. He displayed a higher level of ability for using GST to teach environmental science by understanding how to best incorporate the technology and pedagogy with the content.

Like Teacher E, those who did not feel the external pressures of the school system or state testing and had support from their district or school were able to accomplish more in their classrooms. Teacher C is a representative example of this circumstance:

> We have more freedom within our school because our school’s agenda is one of innovation....They are trying to lead...in innovative, more technologically advanced approaches to teaching. And so from that standpoint we have much more freedom than many might... (Teacher C)

In his classroom, he was able to have more control over the curriculum because of the support and vision of his school and administration.

Even teachers who were able to implement at the highest levels struggled with the curricular issue of how to measure learning within the traditional grading system. For example, Teacher E implemented a highly successful project in an AP environmental science course where students were able to conduct an energy audit, share it with teachers and administrators, and effect change at their school. For this course, students pay a fee and must pass a standardized, rigorous content test to gain college credit. Although the energy audit project was relevant and engaging for students, it did not adequately prepare them for this high-stakes test. The teacher was considering going back to a more traditional way of teaching, because success is conventionally viewed as students doing well on an AP exam. The conflict is obvious. The teacher knew the project was powerful for students but could not reconcile that success with the pressures for the students to pass the AP exam.

Another teaching team also recognized positive student learning outcomes that are difficult to measure with a letter grade:

> We had a kid who [couldn't find available data]....Oh, wow. He was determined to get this on his map. [after teacher encouragement] the kid went nuts....He was just so excited to be able to include that in his thinking....The reward for that was his original thought that would then be recognized in the grading. But beyond that it was just that he knew that he had done something that was not yet available elsewhere. (Teacher B)

The team struggled with how to assess the student project. Teachers and students viewed a rubric as a way to delineate minimum requirements for final student products:

That approach [rubrics] really got great results out of kids, saying, "This is bottom line, but if you want to impress us and get a high grade then show us what you can do. But you really have to say that up front, because kids need to know how they are being evaluated, and that's always the hard part, and we were struggling with that last year. (Teacher C)

Within a system that values grades, and because a numeric grading system was assigned to each category of the rubric, teachers and students had difficulty thinking about the rubric as a communication tool to examine the quality of work and learning displayed and to provide feedback and suggestions for revision.

Finally, successful teachers often had support or found support. If they did not have support at their schools, they sought out community members to collaborate with the class. Community GST experts became mentors to students and may have provided support for teachers who lacked GST skills. Partners in the community also posed problems for students to tackle or acted as an audience of stakeholders to make student projects more authentic. For example, Teacher J teamed up with a university faculty member whose specialty was the fishing industry. Students mapped fish behavior to examine capture methods and freshwater residency. They reported their results to an advisory committee for the Department of Fish and Wildlife.

It is evident that contextual factors played a critical role in whether teachers were able to implement and sustain the teaching practices from the PD. Teachers with strong subject matter alignment, curricular flexibility, and support from their school or districts were able to persist in their teaching practices beyond the PD.

Beliefs

All 10 teachers were coded high in the beliefs category, indicating higher levels of pedagogical knowledge. They mentioned more than three beliefs about teaching and learning aligned with research on effective student learning. They consistently talked about being impressed by students' abilities and how they wanted to provide opportunities for students to "use their brains."

For example, Teacher D identified some issues with implementing inquiry and how she decided to address it: "I think my students really struggled with the inquiry...although these students were bright...they have been pampered....So, instead of doing less inquiry I decided to do more."

Another teacher recognized the importance of allowing students to have ownership over their projects: "But the big GIS projects that we do...are done basically to empower students....The students realized that they have power" (Teacher E). Teachers recognized the importance of allowing students to have choice and the struggle this may involve.

Teachers discussed using current events and local issues to make learning relevant for students and suggested students were more engaged if they could actively explore and analyze data. For example, Teacher F described the following:

> It is my students' future....This is going to be an asset for them....I wanted to bring this tool to them to use as they use tech with their friends. I want them to be that familiar with it....I am excited about the program. I'm getting ready to work with the fire department this summer. They are a big stakeholder. You don't know how important this is. If our students get trained in ArcGIS, they could get jobs. (Teacher F)

Teacher F recognized GST was a means to make learning relevant to students and to supply them with skills that could aid them in future career paths.

Other teachers recognized the importance of making learning relevant, student-centered, and engaging for students, as exemplified by the following quotation:

> Prior to my involvement [in Power of Data] I didn't use any of this stuff and taught traditionally....Students over time had become less and less willing to learn from the 1950's model of education....using technology and using the inquiry based approach, with the students generating questions and the material that they learn, is relevant to their existence....If you package all of those things together I think you make a much happier and effective learning environment for the student. (Teacher J)

None of the teachers in this study fell into medium (only discussing three of the items) or low (discussing fewer than three of the items) categories. However, analysis indicates that high beliefs did not consistently translate to practice.

Technology

Five teachers had high technology skill level using GST. Three teachers had a medium skill level, and two teachers had a low level of GST skill. Technology skill level was predictive of levels of teaching action implementation that were closer to the vision of the

Power of Data project team. We also found that teachers with high technology skill were able to overcome certain contextual barriers. We observed that barriers such as large class size, lack of access to computers or IT support, or lack of administrative support were overcome by teachers with higher technology skills. For example, one high technology teacher at a large urban school had no access to computer labs, but he was able to obtain computers for his class to use for GST projects.

> I joined the [Power of Data] crew and came back with just such a thrill for it and kind of told my administrator, "You know, you signed the paper. What are we going to do? How are we going to do this?" And we were able to scrounge up seven unused computers. And from that we built, we added...additional RAM to [them]. (Teacher E)

This teacher had confidence in his ability to upgrade and maintain the hardware necessary to run the software, indicating his strong technological knowledge.

In comparison to the high technology Teacher E, who overcame his contextual barriers, Teacher G, a medium technology teacher who did not attend the Advanced Institute, was not able to overcome the contextual barriers at his school:

> Last year I had adequate time [to collect data in the field] and that was great. Now we have a problem. I was in a block schedule, for 90 minutes. I'm now in a seven-period day. Fifty minutes. In a 90 minute class, I could actually take my kids out to collect the data. Now I can't take my kids. By the time I take attendance, it's over. (Teacher G)

Teacher G was limited by the changes to the structure and schedule of his classes. He was unable to find ways to complete the work needed in a shorter time frame; therefore, he gave up on implementing in the classroom. In contrast, Teacher F, also a medium technology teacher at a rural high school, had little computer lab access, unreliable Internet, and no support from administration or IT. However, she attended the Advanced Institute where she had an opportunity to practice and learn additional GIS skills. Determined to implement a GST project, she partnered with a graphics arts teacher who had a lot of computers. She was able to add 1 hour each day over an extended period of time for her GST project, thus, overcoming her contextual barriers. Though she had medium technology skills, she sought out someone with higher skills to help.

Teachers in this study were initially characterized by two levels of implementation, mechanical and high. The categories align well with Charles and Kolvoord's (2003) stages of tool use for teachers following the entry stage of PD, (adopt, adapt, innovate): Adapters and Innovators (Table 5). Innovators as a group have high beliefs, high actions, high technology skills, and medium to high context compared to the Adapters, who also have high beliefs, but are low to medium in technology, actions, and context. In this study, five stand out as Innovators and five as Adapters. Using these categorizations, illustrative case summaries were developed to describe these stages of teachers.

Innovators. Innovators were high in both beliefs and actions and displayed higher levels of ability to integrate technology within their context. Qualities that exemplify Innovators included the teacher not only believing the learning should be relevant, authentic, and experiential for students, but also acting upon these beliefs by implementing lessons that exemplified those stated convictions.

Table 5
Innovators and Adapters

Teacher	Category	Teaching & Learning Beliefs	Teaching Context	Technology Ability	Teaching Actions
A	Innovator	high	high	high	high
B	Innovator	high	high	high	high
C	Innovator	high	high	high	high
D	Innovator	high	medium	high	high
E	Innovator	high	medium	high	high
F	Adapter	high	low	medium	med
G	Adapter	high	low	medium	low
H	Adapter	high	low	low	low
I	Adapter	high	medium	medium	low
J	Adapter	high	medium	low	low

Because they had higher technology skill, the Innovators orchestrated experiences for students that included conducting fieldwork, analyzing spatial data, and working directly with and making presentations to community stakeholders. These teachers believed all students could learn and provided opportunities for students to explore their world and struggle with real problems. The teachers understood that the power of GST lies not in the technology itself, but in its potential to build spatial thinking, scientific practices, and 21st-century skills in students. Innovators were risk takers and willing to cede control and learn alongside the students. They encouraged students to explore data in a GST and then create new products for communication using GST.

Some evidence indicated that the initial required implementation and resulting evidence of student learning influenced Innovators to continue. Teacher E came into the program with high technological knowledge; he was pursuing a graduate degree in GIS and had the technical ability to create his own classroom lab, load the software, and troubleshoot. He also hinted at his tendencies to modify lessons to meet his students' needs, indicating his knowledge of pedagogy and content:

> We had really...poor screens to start out with, I mean hand me, hand me, hand me downs....Then also we had to upgrade the RAM. We were given 1 gig and that was just crashing terribly. And so we had to find the funding to up that, and we did.
>
> I just modified [the lessons provided in PD] a little bit...based on what I saw the first time I used it. I was taking on a lot as a teacher as my first year of teaching AP. It was my first year getting a lab up and running in my classroom that could use GIS. So there's a lot of firsts in there. And so I kind of stumbled through the lesson. But I also did find some really good points and some really good things to change and to utilize. So I'm using it again. Claims and evidence, we did that....It's all really based on the real world problems. (Teacher E)

Another Innovator teaching team talked about how they had used similar pedagogical skills before the program, but refined them as a result of the PD. In an interview with the two teachers, they discussed the following:

> I think the Backward Design and the problem-based approach we have found to be a really fantastic idea, and it has pretty much structured what we've done in the course, both the last year when we were doing it for [the PD program] and this year as the follow-up year. (Teacher B)

> Even before that we had used a similar thing not quite as well structured, but a similar approach....[Students] knew that the courses that I would teach, they would not be deadbeat courses. They wouldn't be courses that are just timekeepers. They would be doing something where they would have to, you know, use their brain, and they like that....That's the expectation. If you can perform and analyze and tell me responses that make sense that you can draw from the data you have that are appropriately linked, yeah, you'll be fine. (Teacher C)

The teachers began with high, standards-based expectations for their students and described that students would need to analyze spatial data critically using GST in order to make claims based on these data. These behaviors indicate an advanced understanding of pedagogical practices within their context.

Innovators like Teachers B and C held high expectations for their students and encouraged students to develop 21st-century skills through their interaction with the technology. Innovators recognized important concepts that could be enhanced by the examination of spatial data within a GST. They identified authentic connections and provided opportunities for students to analyze and present evidence-based explanations and solutions based on these data collaboratively to stakeholders.

Adapters. In comparison, Adapters were successful in adapting and teaching at least once a lesson that was provided during PD, but often began to revert to adopting lessons as written in GST texts. Adapters had lower technological skills and were generally more comfortable using resources and data already created. They frequently played the role of deliverer of knowledge. Adapters preferred a more controlled classroom environment. After the PD had ended, they continued to teach with GST to some degree. The pedagogical practices presented during the Power of Data PD were persisting in their classrooms at some level. However, there was something preventing these teachers from fully teaching in the way they expressed was best for student learning.

Teacher J is an example of an Adapter. Initially, this teacher's students tackled a local issue with the help of GST professionals and local wildlife scientists, indicating some understanding of the importance of students engaging in an authentic problem. A year later, the teacher sounded like an Innovator, emphasizing teaching "using the inquiry-based approach" and "students generating questions." Yet, the actual teaching observed in this classroom was a traditional teacher-centered lecture on current natural disasters. The lecture was followed by computer lab time in which students followed a set of step-by-step instructions. Instructions guided them to examine 15-year-old data sets provided by the teacher and answer low-level questions provided on a traditional worksheet.

The assessment of this lesson was provided by the curriculum and required students to create an evacuation plan for inhabitants rather than make a claim about how populations are affected by weather events, which was the goal of the lesson, according to the teacher. This instruction somewhat followed the model provided in PD, but based on our definition of *teaching action* (Appendix F) this lesson fell on the low end of implementation practices.

Additionally, contextual barriers such as time, curricular flexibility, and access to computers were sometimes more than could be overcome. For example, one Adapter said, "...You can't do this in a 50-minute period unless you have a lab setting. In a public school, that's kind of hard" (Teacher G). Another Adapter said: "So we use the *Mapping Our World* lessons [GIS text] to kind of supplement, or to give the kids a break...." (Teacher I).

These statements exemplified typical views held by the Adapters*:* that GST is a skill taught in isolation, as an elective course, or to supplement instruction. Overall, they placed an emphasis on teaching about the capabilities of the technology rather than on utilizing the technology as a tool to help students develop content understanding through data analysis and for communicating ideas. Adapters viewed the GST as a skill to learn that is tangential to the content learning. They did not see GST as important for helping students analyze spatial data to find patterns, understand content, or communicate ideas.

Discussion

The goal of this study was to determine if teachers who implemented lessons at a mechanical or high level during PD would continue to implement 1 to 2 years following PD and to what extent they would implement. The intent was to determine which practices they sustained and in what contexts and to attempt to characterize teachers who persisted in these teaching practices.

Persistent Pedagogical Practices

Evidence demonstrates that practices consistent with teachers' goals for student learning persisted following the PD. Participating teachers all implemented GST-integrated lessons at an innovate or adapt stage. PD emphasized the importance of allowing students to experience learning science as scientists do by engaging in the practices of science around authentic issues. Teachers recognized career connections and the potential of GST to engage students who are interested in technology but might not normally be drawn to the natural sciences. Teachers experienced the collaborative use of GST to explore solutions to problems and built on the strengths of team members during PD. These practices were also enacted in their classrooms.

This model resonated with teachers. They saw the value of implementing lessons for developing 21st-century workforce skills, such as critical thinking, collaboration, and communication. They engaged community members as stakeholders to provide an authentic context and gave students the opportunity to work in teams to explore geographic questions. Teachers recognized the cross-disciplinary nature of GST tools and wanted to give their students opportunities to engage with the technology as well. PD providers should keep these unique affordances of GST in the forefront as they work to support teachers to teach with GST.

Teachers with less-developed technology skills were more likely to implement if they had materials and datasets that could be adapted to fit within their curricular needs. This finding is consistent with literature on coherency and best practices for GST PD (Kolvoord et al., 2014; Moore et al., 2014; Stylinkski & Doty, 2014). Our findings further confirm the importance of providing teachers with resources and supports during PD, especially those with lower technology skills.

In order to see higher levels of implementation continue, more time should be spent on developing the technology skills of science teachers. This study does not address whether teachers learned GST skills better within the context of engaging in a real-world problem than they would have learned it in isolation. However, participants had the opportunity to experience some of the limitations and abilities of the tool for teaching specific Earth science concepts during PD, which may have been helpful for learning. As Baker et al. (2015) recommended, additional research is needed to determine if the use of GST in different content areas require different levels of technological and pedagogical skills. We are currently conducting a design-based research study to determine if the Power of Data PD model can be translated into new contexts to achieve similar desired outcomes.

Persistence of practice and implementation of the integration of GST within PBI must occur after PD ends or the sustainability of the positive results experienced during the PD will not persist. If teachers are able only to implement with support from PD staff, GST will never see widespread use.

Context Supports and Limitations

Based on the experiences of all the teachers studied, four critical contextual factors were identified as especially important for persistence of practice: subject matter alignment, curricular flexibility, assessment, and support. Implementation within the context of a traditional school system plays a huge role in determining what practices persist.

Our goal was improved teacher instruction and use of technology to bring authentic learning to the classroom. We wanted teachers to use data to help students visualize phenomena, look for patterns, and propose solutions to authentic problems using data as evidence for claims. We were focused on implementation leading to improved student learning as a measure of success.

However, in spite of these goals and PD provision, traditional school systems constrained teachers, and structured courses dictated what should be taught and how students should be assessed. Those teachers who recognized and described student learning similar to our definition and the definition in the literature (Krajcik et al., 1999) were more able to persist with the practices presented in the PD. They had such high beliefs in the value of teaching with GST and PBI that they made it work by squeezing it into an overloaded curriculum or offering a special elective course.

Those teachers who did not recognize the value or who ran into too many barriers were less likely to persist with the initial change in their practice following implementation. This finding is consistent with the literature that context will determine persistence (Borko, 2004; Desimone, 2009; Penuel et al., 2007). Perhaps expecting teachers to be innovating constantly is unrealistic. High levels of innovation are difficult to maintain, and if teachers are utilizing existing high-quality GST lessons from texts, even if the lessons are not authentic, it is a step in the right direction. Regardless of the level of innovation, we can still celebrate the fact that students are being exposed to spatial analysis and GST tools.

Sadly, authentic GST-integrated projects that stress relevant learning and build students' 21st-century workforce skills may never truly fit into a traditional science course. These types of projects may be doomed to be on the fringes of curriculum—something to be experienced as an elective or add-on if all the other requirements are met or only for those students who have time in their elective schedules. It is time to ask the questions: What is the purpose of required science courses? Are they solely for content learning, or are the tools of scientists important to learn as well? Do GST-integrated projects fit better in lower level, introductory courses, in order to encourage students to consider additional courses in STEM? Is the goal to prepare the workforce of tomorrow or to prepare students for college readiness? Must teachers dispense critical science knowledge or have students understand and appreciate the nature of science? Moving forward, school systems and the science education community need to reflect on these questions.

Characteristics of Persistent Teachers

Shulman (1986) identified pedagogical content knowledge as the ability of an expert teacher to understand how specific content is best taught and communicated through appropriate lesson design. Koehler and Mishra (2005) added technology to the discussion to describe technological pedagogical content knowledge (later referred to as technology, pedagogy, and content knowledge, or TPACK). Cox (2008) defined TPACK as the “transactional negotiation” between these elements and noted that essential features include choosing appropriate technology for teaching specific content using a particular pedagogical strategy within an educational context for a particular student learning goal.

Although the teachers we described as Innovators struggled with fitting new ways of teaching into a traditional grading and school system and realized GST projects could not meet prescribed curricular goals/standards, these teachers persisted, perhaps due to their higher levels of GST skills and knowledge and implementation of the pedagogy. They created electives and special courses to allow students to complete authentic projects. These types of courses are often implemented after students have completed required courses and go above and beyond graduation requirements. All of our Innovators had to take risks and approach their administrators to create pathways for students. All of the teachers had a strong understanding of how to integrate pedagogy in their disciplines, and most teachers were experienced in their fields. Adding technology or pedagogy to their repertoire strengthened their teaching practices, as they developed their understanding of how GST could enhance their instruction.

Rogers (2003) described a diffusion of innovation as it progresses from the innovators to early adopters, early majority, late majority, and laggards through normal distribution across social systems. Horsley and Loucks-Horsley (1998) described change as a process and stated that changes in classrooms can take up to 5 years to materialize. This timeline has been found to be true with GST integration also (Baker & Kerski, 2014).

Kolvoord et al. (2014) illustrated cases of teachers as they progressed through stages of concern: entry, adopt, adapt, and innovate. The teachers in our study were at different points along the adoption continuum and experienced natural stages of concern as they progressed at their own pace. Those who persisted were further along the continuum of learning.

In the current study, we recruited teachers who could explain how they were already implementing PBI or student-centered, inquiry-based methods. We asked them to describe how they were currently integrating technology into their classrooms. We chose teachers who were naturally more ready to progress in their practice, then we focused on building their understanding of how to incorporate GST in the areas where they needed more support. This strategy led to teachers who were in the adapting and innovating stages and whose practices persisted at some level beyond the PD. Studying whether targeted assessment of existing TPACK components followed by individualized interventions would yield higher levels of TPACK and implementation after PD support ends would be interesting (Baker et al., 2015).

For many teachers, PBI is a novel way to teach. If a teacher is new to PBI, layering complex technology on top of it makes PBI more challenging to implement, especially when educational institutions value academic test performance over less-traditional learning outcomes, such as problem solving and communication skills. Knowing this, PD providers must offer differentiated support to teachers that meets their needs and builds upon their individual knowledge and skills as they adopt new teaching methodologies within their particular contexts. In other words, their abilities should be built through differentiated PD.

Limitations

All teachers in this study believed that students should learn through experience and had high expectations for students. It is not possible from our data to determine whether the teachers came into the program with these beliefs, found the PD to be consistent with their existing beliefs and, thus, continued to implement lessons with GST, or if the PD influenced their beliefs, or if beliefs changed as a result of implementing and seeing student learning gains, as Guskey (2002) surmised. Because all teachers' beliefs were coded as high, context seems to be the most influential mediating factor.

Conclusion

This study described teachers with varying technology skills who were implementing GST and PBI at many grade levels in various contexts, while maintaining consistently high beliefs about teaching and learning. From these findings, we delineated contexts that must be addressed as PD providers to encourage persistence of practice. Like others, we found the keys to helping teachers persist with even the most mechanical levels of implementation involve access to software and resources that integrate technology with subject matter, support from administrators who understand the benefits of these practices (including allowing extended periods of time and curricular flexibility required for PBI) and having a partner in the school or the community who also supports efforts (Baker et al., 2015; Claesgens et al., 2013; Kerski, 2003; Mumtaz, 2000).

Guskey (2002) stated that for PD to be effective teachers must learn and implement before student learning and a change in beliefs can occur. The teachers in our study were satisfied with PD, learned from the experience, applied their newfound knowledge and skills in the classroom, and recognized initial positive student learning outcomes. Upon closer examination, however, and looking 1 to 2 years past the PD, the practices some teachers originally enacted did not sustain at their highest stage (adaptation or innovation). Some teachers, when faced with classroom constraints, fell back to using materials as written.

Although all the teachers in this study expressed similar beliefs about teaching with GST and the power of allowing students to conduct inquiry using relevant data, and all were continuing to teach with GST to some degree, they were not all able to teach with pedagogical practices that aligned with these beliefs. Science educators want to see action that is consistent with beliefs, yet the observed mismatch is consistent with research in teacher education (Mansour, 2009).

In spite of high beliefs, teachers displayed a range of teaching actions. Contextual factors were more predictive of action than belief, yet context was not the only factor. Certain teachers were able to overcome contextual barriers.

Coulter (2014) asserted that teacher competence, capacity, and readiness is critical before GST can be successfully integrated into classrooms. Our findings support this assertion. Similar to other findings, teachers in our study who were most successful with implementing lessons were teachers who knew their content well and were actively seeking new ways to engage students (Baker & Kerski, 2014; Kerski, 2003; Kolvoord et al., 2014).

Our research illuminates teachers' beliefs that students should struggle with data and solving problems; they know it empowers their students. Unfortunately, similar to what Baker and Kerski (2014) reported about teachers in the 1990s, teachers often find measuring and recognizing authentic, real-world student learning outcomes to be difficult, especially when the traditional academic establishment defines success as student performance on standardized exams. A prevalent, though possibly misguided, focus on grades persists as the most important measure of student learning. This focus on grades appears to impact the pedagogical approaches teachers are willing and able to take with respect to the implementation of GST in their classroom. If evidence of higher student learning gains as a result of teaching and learning with GST can be effectively measured and gathered, implementation may increase.

MaKinster and Trautmann (2014) and Coulter (2014) stressed that in order to be successful at teaching science with GST, teachers need strong TPACK to develop and guide students through authentic, geospatial inquiries. We did not explicitly measure teacher levels of TPACK in this study but our findings are somewhat consistent with this idea. We are intrigued by the work being done to better define the construct of TPACK. We agree with Rosenberg and Koehler (2015) that instruments must be developed to measure teachers' existing and growing TPACK more accurately, taking into account the critical element of context, which we have found to be the most influential mediating factor to implementation.

If it can be accurately measured, PD efforts must focus on building teachers' TPACK when teaching with GST. Supporting teachers to move to higher levels of implementation and sustained pedagogical practice will require additional learning experiences to help them see beyond the technology itself and how to utilize and integrate technology within PBI to meet curricular goals. Additional research to determine which learning experiences might advance TPACK growth the most and knowing when interventions are most effective is necessary before moving forward (Baker et al., 2015).

A possible way to connect the dots to build teacher TPACK is the PBI framework. PBI seemed to resonate with teachers in this study. PD providers can introduce this as a pedagogical strategy that results in student learning. Even if the driving question is not completely authentic, it provides students with a reason to engage in the analysis of geospatial data using GST. PD providers can help teachers consider what specific content might benefit from a geospatial perspective and which geospatial analyses and technical skills are most appropriate and necessary to support the investigation.

Teachers need help crafting driving questions centered on disciplinary core ideas. Once the driving question is established, teachers can build cohesive units of instruction that culminate in students' developing evidence-based arguments or explanations of scientific phenomena. Teachers should recognize how each investigation of geospatial data helps students develop a bit more understanding of the content that will allow them to come closer to answering the driving question. Obviously, any investigations that do not contribute to students' explanations or arguments should be eliminated.

Beyond the integration of technology and consideration of pedagogical strategy, teachers need guidance in the assessment of student learning that might differ from the traditional assigning of grades. Experiences should also assist teachers to articulate and measure 21st-century skills, such as collaboration, creativity, communication, and critical thinking. This organizational support and change is critical for persistence of new pedagogical practices following PD. Perhaps as teachers implement student-centered teaching methods that engage students in the practices of science and 21st-century skills and recognize learning gains that cannot be measured on standardized tests, school systems will also acknowledge these methods as beneficial for learning and support their use.

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Appendix A

Project Planning Form – Local Water Resource Analysis

Begin with the End in Mind

- Water distribution and cycling on Earth
- Human use of and impact on water
- Colorado distribution of surface and subsurface water supplies, related to population
- Local County water sources and population impact

Identify the content standards that students will learn in this project

Colorado Earth Science Content Standards – High School: There are costs, benefits, and consequences of exploration, development, and consumption of renewable and nonrenewable resources.

Evidence Outcomes – Students can:

a. Develop, communicate, and justify an evidence-based scientific explanation regarding the costs and benefits of exploration, development, and consumption of renewable and nonrenewable resources
b. Evaluate positive and negative impacts on the geosphere, atmosphere, hydrosphere, and biosphere in regards to resource use
c. Create a plan to reduce environmental impacts due to resource consumption
d. Analyze and interpret data about the effect of resource consumption and development on resource reserves to draw conclusions about sustainable use

National Science Education Standards – Science in Personal and Social Perspectives: Content Standard F, grades 9-12, Specifically:

a. Populations can reach limits to growth. Carrying capacity is the maximum number of individuals that can be supported in a given environment. The limitation is not the availability of space, but the number of people in relation to resources and the capacity of Earth systems to support human beings.
b. Human populations use resources in the environment in order to maintain and improve their existence. Natural resources have been and will continue to be used to maintain human populations.
c. The earth does not have infinite resources; increasing human consumption places severe stress on the natural processes that renew some resources, and it depletes those resources that cannot be renewed.
d. Natural ecosystems provide an array of basic processes that affect humans. Those processes include maintenance of the quality of the atmosphere, generation of soils,

control of the hydrologic cycle, disposal of wastes, and recycling of nutrients. Humans are changing many of these basic processes, and the changes may be detrimental to humans.

Craft the Driving Question

Where does your water come from, how is it used, and can current population growth trends continue while maintaining a sustainable water supply?

Performance Objectives/Targets-

Early:

By modeling water distribution on Earth and graphing the results, students will illustrate how a finite water supply on Earth is distributed Among different sources (graph and summary statement)

By following the many routes of a water molecule through a complex branching water cycle (Hydro), students will organize the various sources and sinks of water in the cycle and create a schematic (poster, graphic, Inspiration web) of the sources and sinks

Through Internet research, students will evaluate the many human uses of water and the possible disruptions of water availability or quality that result from each use (written document, poster, or PowerPoint)

During:

Using GIS, students will calculate surface water availability per capita in the state of Colorado and analyze the visualization. Based on this analysis, they will assess possible conflicts due to different human uses for the water and availability throughout the state. (Map of surface water riverflow data; map of population; map of land use; map of surface water per person; written document, poster, or powerpoint for analysis summary)

End:

Through their research and analysis, students will determine the source(s) and uses of their local water supply. Based on understanding of current population growth trends in the area, they will compile possible threats to their water quality and quantity and propose community action to protect a sustainable water supply.

Plan the Assessment

Step 1: Define the products and artifacts for the project:

Early in the Project:

Water Sources – Graph and Summary Statement comparing predicted and actual % of total water stored in different water sources.

Water Cycle- Inspiration Water Web detailing sources and sinks in complex water cycle

Water use and population impacts – Option: Essay, Poster, Powerpoint

During the Project:

GIS Products – 3 Layouts detailing water availability, population, and water availability per person – Option: Poster or Powerpoint

End of Project:

Presentation of recommendation to the community – Visual Display and Oral Presentation, including source(s) of local water, uses of local water, local population trends, threats to water supplies, proposal for community action to protect a sustainable water supply.

Map the Project

Product: PowerPoint or Poster, including GIS layouts, summary compilations, recommendations

Knowledge and Skills Needed	Already	Before	During
Know water distribution on Earth		X	
Know complex water cycle		X	
Have Internet research skills	X		
Know ArcMap skills		X	X
• Add data		X	X
• Perform math operation on data		X	X
• Selection criteria		X	X
• Display decisions		X	X
• Produce layouts		X	X
Know local water source(s) and population			X
Presentation skills	X		

Map the Project:

Week 1	Where is the water activity	Hydro Water Cycle Webbing Activity	Research Water Use and Population Impacts	
Week 2	GIS-Introduction using state riverflow data and population as context	Adding data, basic operations, math operations	Selection and display options, Layouts	Form groups Set project expectations
Week 3	Research local water sources, use, population growth statistics	Group work on final project	Group work on final project	Presentations-Gallery tour (Peer and others review)

Rubric Template:

Component	Level 0	Level 1	Level 2
Claim- An assertion or conclusion that answers the original question.	Does not make a claim, or makes an inaccurate claim.	Makes an accurate but incomplete claim.	Makes an accurate and complete claim.
Evidence- Scientific data that supports the claim. The data needs to be appropriate and sufficient to support the claim.	Does not provide evidence, or only provides inappropriate evidence (Evidence that does not support the claim.	Provides appropriate, but insufficient evidence to support claim. May include some inappropriate evidence.	Provides appropriate and sufficient evidence to support the claim.
Reasoning- A justification that links the claim and evidence and shows why the data counts as evidence to support the claim by using appropriate and sufficient scientific principles.	Does not provide reasoning, or only provides reasoning that does not link evidence to claim.	Provides reasoning that links the claim and evidence. Repeats the evidence and/or includes some scientific principles, but not sufficient.	Provides reasoning that links evidence to claim. Includes appropriate and sufficient scientific principles.

Plan the Assessment:

Step 2: State the criteria for exemplary performance for each product:

Product:	Graph of Global Water Distribution
Criteria:	Using scoring rubric: Data correct and complete Axes labeled and scaled correctly Quality Criteria (neat, color-coded)
Product:	Water Web or Graphic
Criteria:	Rich display of sources and sinks , specify # of each required Quality Criteria (neat, pleasing) Demonstrates complexity of cycle (vs. simple single cycle)
Product:	Poster/PowerPoint
Criteria:	Specify x # human uses, with matching impacts Extension into specific uses/impacts of local water Summary based on evidence gathered Source documentation and references (#) Quality Criteria
Product:	GIS Products Presented in Poster/PowerPoint
Criteria:	4 layouts Quality Criteria: correct, well-organized, visually pleasing Description of potential conflicts and consequences # based on data and analysis Quality Criteria
Product:	Poster or PowerPoint or……
Criteria:	Content: Correct results of research Water sources ID'd Human Uses ID'd source documentation and references (#) Population Growth Projections Description of threats to quality and quantity # based on data and analysis GIS Visualization and Presentation

Layout(s) including required data
Display of Summary Points
#
based on data and analysis
Proposal for Community Action
#
based on data and analysis
Presentation Quality Criteria

Climate Change Site Mitigation Plan

Identify course objectives	These are statements of what a student will know and do as a result of instruction: Through watershed and stream system analysis, data collection across the region, and climate models that predict changes in climate and weather events in the area, students will identify factors that might affect an assigned area of the city that sits on the Rio de Flag stream system and develop a comprehensive plan for site modification in the short and long term.
Big Idea/Concept	Explain how solar energy is transferred to different forms on Earth and how this energy modifies the Earth system via stream systems.
The CHALLENGE	Design challenges for instruction – these are statements that pose a complex goal to the students. Interesting challenges engage students in a process of inquiry that requires them to apply the desired concepts beyond simple manipulation of mathematics. (Anticipatory set or Engage; GIS workflow: Define the problem or scenario) The City of Flagstaff is planning to develop an area surrounding downtown, but there is a river, the Rio de Flag, that runs straight through several of the proposed areas. You have been tasked to report to the community planning committee the likely behavior of the stream system in the short and long term, and develop a plan to mitigate possible problems. The Earth's climate is likely to change, so plan for these changes in the long term and propose a sustainable improvement and site management plan.
<u>Lesson Introduction/Summary</u> **GENERATE IDEAS**	Students have an opportunity to explore what they currently know about the challenge. This includes their naïve concepts or models of the domain and will provide a baseline or pre-assessment of what they know about the challenge. (Elicit Prior Knowledge) Some things to consider: • Different areas respond to change in different ways • Extremes of seasonal weather may increase • Severity of individual storms may increase • Changes in precipitation amounts • How and when precipitation occurs (snow vs. rain)

	Target Questions for Generate Ideas: • What are some things that might affect how a stream system behaves or where a watershed begins and ends? (ex: Sharp bends, changes in width, type of soil or bedrock, pervious and impervious surface cover, drains and culverts, and vegetation growth, divides) • What factors might you need to consider when proposing improvement plans? (ex: Stakeholders, infrastructure, recreation)
MULTIPLE PERSPECTIVES	These are statements by "experts" describing what they see in the challenge. Their comments provide insights into various dimensions of the challenge, but do not provide a direct solution to the challenge. Students can compare their initial thoughts with the experts. (Explore or Point out/present important information, Input, Modeling) 15 minutes at most City of Flagstaff ideas for floodplain management and Rio de Flag plan? Rio de Flag watershed maps?
RESEARCH AND REVISE	Students engage in a series of learning activities (such as simulations, lectures, homework, labs, and readings) designed to help them focus on the important dimensions of the challenge. These activities are designed to help the students make a link to the original "Challenge." (Explain or Guided Practice) • Stream Table Activities from Landforms – FOSS Kit • GIS Investigations on Rio de Flag floodplain zonation • Rio de Flag Basemap Creation and Investigation using Historical Aerial Photos • Fieldwork and data collection • Lectures/Presentations on flood hazards, flood mitigation, stream processes
TEST YOUR METTLE	This assessment method (homework questions, online quizzes, essays, etc.) provides students the opportunity to apply what they know and evaluate what they need to study more. It also allows the students to reflect on how well they've learned the content and to evaluate if they are ready to Go Public with what they know. (Elaborate or Check for Understanding) Apply what was learned to their particular city using GIS to create a presentation Identify the deliverables needed to support the decision (maps) In applying GIS to a problem, you must have a very clear understanding of the problem or scenario.

	We find it helpful to answer these four questions, which test your understanding and divide the problem into smaller problems that are easier to solve. **Q1** *What geographic area are you studying?* **Q2** *What decisions do you need to make?* **Q3** *What information would help you make the decisions?* **Q4** *Who are the key stakeholders for this issue?* Identify, collect, organize, examine the data needed to address the problem. Document your work Create a process summary Document your map Set the environments Prepare your data Create a basemap or locational map Perform geospatial analysis Produce deliverables, draw conclusions and prepare a presentation for a scientific convention.
GO PUBLIC	This is the final assessment of what students know at the end of the module. This assessment could be a presentation of the content, a quiz or test, an essay, homework, etc. (Evaluate) • Presentations shared in scientific convention • present the results
LOOK AHEAD AND REFLECT BACK	Elaborate, apply to a new situation

Appendix C

Proposal: Grand Canyon Ecology GIS Unit

Theme/ Big Idea	Human beings are part of the earth's ecosystems. Human activities can deliberately or inadvertently alter the equilibrium in ecosystems.
Content Standards (National)	**Science in Personal and Social Perspectives** <u>Natural and Human-induced hazards</u> Natural and human-induced hazards present the need for humans to assess potential danger and risk. Many changes in the environment designed by humans bring benefits to society, as well as cause risks. Students should understand the costs and trade-offs of various hazards.
Content Standards (Arizona)	**Strand 3: Science in Personal and Social Perspectives** **Concept 1: Changes in Environments** Describe the interactions between human populations, natural hazards, and the environment. **Concept 2: Science and Technology in Society** Develop viable solutions to a need or problem. **Concept 3: Human Population Characteristics** Analyze factors that affect human populations.
Identify key skills students will learn	Collaborate Critically solve problems
Identify district or school or district outcomes in this project	Rigor – Higher levels of Blooms Taxonomy
A need to know (motivator)	Yellowstone Fire (Playing God in Yellowstone book) Wallow Fire Grand Canyon Fire
Essential question or problem	The Wallow Fire burned 519,319 acres costing more than $53 million taxpayer dollars. How can we prevent or minimize the impact of fire in our state treasure – The Grand Canyon.
Define the products and artifacts for the project including criteria	**Early** (Identify misconceptions and ideas) Take a Stand – Rank Fire good/ bad, fold and discuss **During** (Formative Assessment – artifacts) Notebook and Classroom Discussion • Demonstrates clear understanding of concepts for each of the objectives • Teacher to use this as a tool to check understanding **End**: (Summative Assessment) Student Proposal / Recommendation Criteria: • Use GIS data to show the problem • Applies fire ecology theory in identification of problem • Evaluates how to best address the problem • Integrates GIS data and fire ecology theory to produce a carefully planned solution.

Map the Project	**Students evaluate fire based on prior knowledge.** Take a Stand Yellowstone Fire - http://www.youtube.com/watch?v=pNhaZHyiE1s Big Question: What impact would a large fire in the Grand Canyon have on Arizona? KWL - wildfire
	Students will use GIS to measure Wallow Fire and predict future fire activity in given conditions Resources: Wallow geodatabase including native vegetation and Wallow fire geoimage (Wallow _fire.mxd) Homework: Why study fire Close: Add to KWL
	Students will develop scenarios that present a variety of environmental factors and predict their impact on possible fire in the area. Brainstorm environmental factors that impact fire behavior. Homework: Read Weather, Fuels and Topography Handout Assessment: Student choice of transmission method matching objective above. Close: Add to KWL
	Students will compare and contrast a variety of fuels and their contribution to fire based on weather and fuels lab. Weather and Fuels Lab Close: Add to KWL
	Based on the topography and fuel density lab students will evaluate the wildfire potential for a given topography. Topography and Fuel Density Lab Close: Add to KWL Homework: revisit Wallow fire prediction and revise as necessary – see Wallow Fire Rubric. (Wallow _fire.mxd)
	Students will evaluate a fire ignitions in GCNP to determine where most fires are started and the source of most fires. Fire ignition mxd will be symbolized to determine the cause of most fires, location and size of most fires. Students will use the map analyze the data and to present their findings

	Students will criticize or define fire suppression based on the movie Fire Wars and Fire on the Landscape Handout. Fire Wars Movie Students create a roleplay demonstrating the various points of view represents Close: Add to KWL Homework: Read Fire on the Landscape Assessment: Fire Suppression Rubric
	Students will create criteria to assess if a fire was a high-intensity fire or a low intensity fire after participating in the Fire and the Web of Life Activity. Fire and the Web of Life Close: Add to KWL
	Students will compare and contrast Ponderosa, Pinyon and Juniper Woodland ecosystems from Internet research.
	Students will use their knowledge of Ponderosa pine adaptation to create a tree that will not burn under low-intensity fire conditions.
	Students will use GPS devices and cameras to collect forest data about fuel load. (Teacher to load Lat/Long data and set up tables for students to use.)
	Students will assess the fire potential based on GIS map. Introduction: Fire Potential MXD Show the same map with different symbologies. Have the students determine which is more informative and why. Demonstrate how to create symbology. Students will use the already created map with data about fuel load. They will use symbology to analyze and predict areas with greater fire load. Students will use maps to support their point of view. Fire Potential Rubric
	Students will create a GIS map that compiles fuel data collected. They will return to the school and input data into a standardized format table with possible subtypes to prevent input error table created by their teacher. (Teacher to append tables for later use) Grand Canyon MXD

	Students will compare and contrast fire management options and students will propose a plan of action for a given situation. Management Choices Activity Close: KWL
	Students will create a proposal to limit the fire potential in the area of investigation. GIS Activities: Import Points Create Slope from DEM file Add Photos to points Students will create a proposal supported by their map on how to handle fuel overload in the areas that they investigated in the Grand Canyon. Fire Management Choices Rubric

Data sources used: -

http://fia.fs.fed.us/tools-data/default.asp

GCNP data files obtained from NAU (Mark Manone)

Natural Resource Information Portal (GIS data source for National Parks)

Lesson References:
http://www.nps.gov/grca/forteachers/loader.cfm?csModule=security/getfile&PageID=523000

Rubrics

Wallow Fire

Students will predict the progression based on information given. They need to make a claim and justify that claim with evidence from the map and fire incident website http://inciweb.org/incident/2262/ and June 15, 2011 Landsat 5 satellite image http://earthobservatory.nasa.gov/NaturalHazards/view.php?id=51064

		Level	
Component	Unsatisfactory (Below Performance Standard)	Proficient (Acceptable)	Advanced (Demonstrates exceptional performance)
Claim: An assertion or conclusion that answers the original question	Does not make a claim or makes an inaccurate claim -- *States that the fire will jump to Washington state*	Makes an accurate but incomplete claim -- *Vague statement like "the fire will continue to burn"*	Makes and accurate and complete claim -- *Explicitly states "The fire will move in a southerly direction until it runs out of fuel"*
Evidence: Scientific data that supports the clai. The data needs to be appropriate and sufficient to support the claim	Does not provide evidence or only provides inappropriate evidence. (Evidence that does not support claim) -- *Provides no evidence for fire prediction, inaccurate evidence ("the elements of fire are not present")*	Provides appropriate but insufficient evidence to support claim. May include some inappropriate evidence -- *Provides evidence for fire prediction based on only one or two of the factors that impact fire.*	Provides appropriate and sufficient evidence to support claim -- *Provides evidence for fire prediction based on three or more of the factors that impact fire.*
Reasoning A justification that links the claim and evidence and shows why the data counts as evidence to support the claim by using the appropriate and sufficient principles	Does not provide reasoning or only provides reasoning that does not link evidence to claim or provides incorrect reasoning. -- *Provides inappropriate statement ("because that is what I think") or incorrect reasoning ("wind will blow the fire out")*	Provides reasoning that links the claim and evidence. Repeats the evidence and/or includes some scientific principles but not sufficient. -- *Justifies prediction by explaining how one or two factors impact fire. ("Fire needs oxygen and additional oxygen is being provided by…")*	Provides reasoning that links evidence to claim. Includes appropriate and sufficient scientific principles. -- *Justifies prediction by explaining how three or more factors impact fire.* *("Factors that impact fire intensity are……*

Fire Suppression Policy

Students will criticize or define the US policy of fire suppression.

		Level	
Component	Unsatisfactory (Below Performance Standard)	Proficient (Acceptable)	Advanced (Demonstrates exceptional performance)
Claim: An assertion or conclusion that answers the original question	Does not make a claim or makes an inaccurate claim --- *States that "all fires are allowed to burn"*	Makes an accurate but incomplete claim --- *Vague statement like "fire suppression has led to problems such as …"*	Makes and accurate and complete claim --- *Explicitly states "The US policy of fire suppression was instituted because… however we now know that…"*
Evidence: Scientific data that supports the clai. The data needs to be appropriate and sufficient to support the claim	Does not provide evidence or only provides inappropriate evidence. (Evidence that does not support claim) --- *Provides no evidence for claim, inaccurate evidence ("fire is never a helpful tool")*	Provides appropriate but insufficient evidence to support claim. May include some inappropriate evidence --- *Provides some correct evidence for claim ("Without fire forests ….")*	Provides appropriate and sufficient evidence to support claim --- *Provides multiples points of evidence for claim. "Without fire forests ….")*
Reasoning A justification that links the claim and evidence and shows why the data counts as evidence to support the claim by using the appropriate and sufficient principles	Does not provide reasoning or only provides reasoning that does not link evidence to claim or provides incorrect reasoning. --- *Provides inappropriate statement ("because that is what I think") or incorrect reasoning ("wind will blow the fire out")*	Provides reasoning that links the claim and evidence. Repeats the evidence and/or includes some scientific principles but not sufficient. --- *Justifies prediction by explaining how one or two factors impact fire. ("Fire needs oxygen and additional oxygen is being provided by…")*	Provides reasoning that links evidence to claim. Includes appropriate and sufficient scientific principles. --- *Justifies prediction by explaining how three or more factors impact fire. ("Factors that impact fire intensity are……*

Fire Potential Assignment

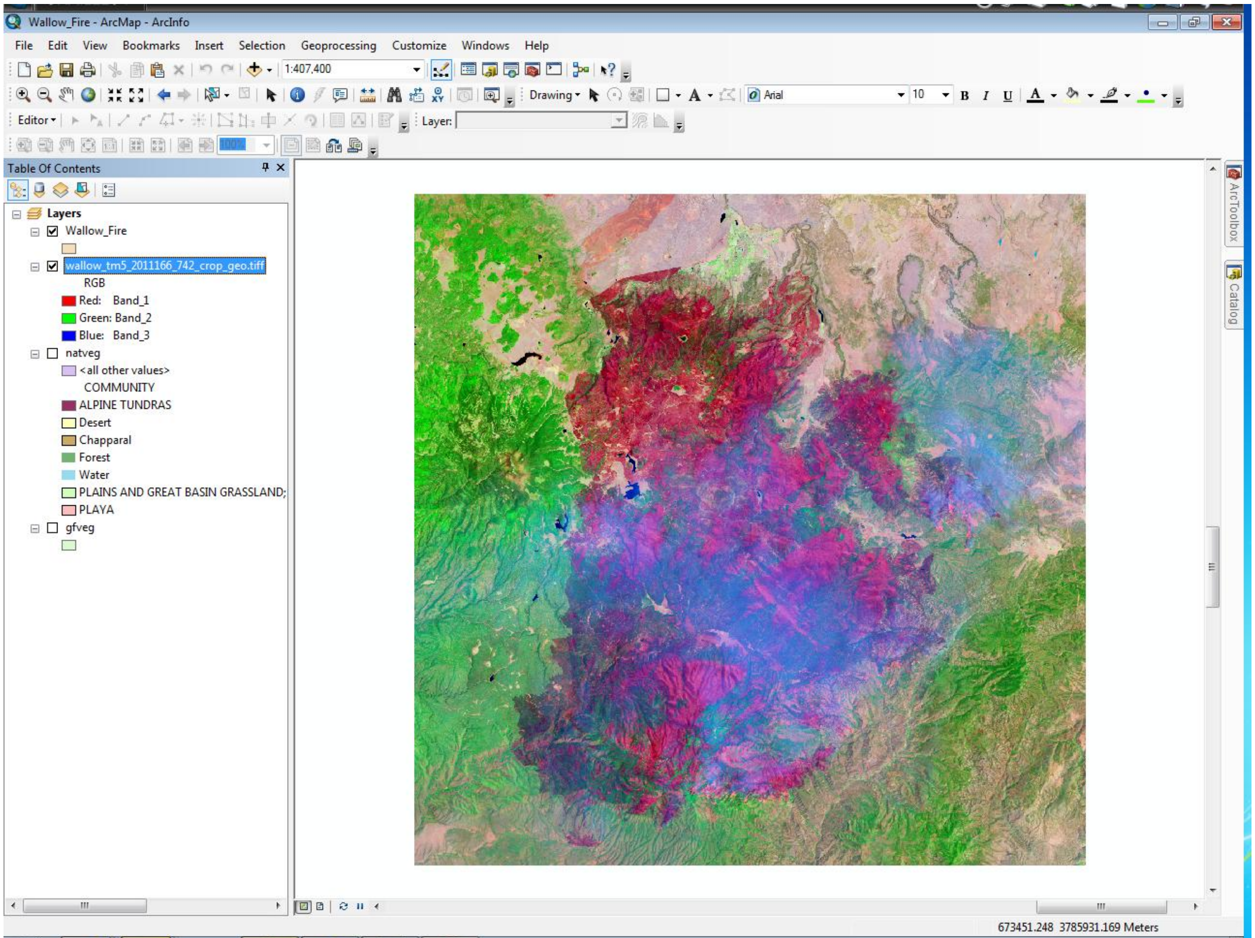
		Level	
Component	Unsatisfactory (Below Performance Standard)	Proficient (Acceptable)	Advanced (Demonstrates exceptional performance)
Claim: An assertion or conclusion that answers the original question	Does not make a claim or makes an inaccurate claim --- States that “fire will burn with the same intensity everywhere”	Makes an accurate but incomplete claim --- n/a	Makes and accurate and complete claim --- Identifies an area with higher fire potential
Evidence: Scientific data that supports the clai. The data needs to be appropriate and sufficient to support the claim	Does not provide evidence or only provides inappropriate evidence. (Evidence that does not support claim) --- Incorrectly identifies areas area of higher fire potential	Provides appropriate but insufficient evidence to support claim. May include some inappropriate evidence --- Provides some GIS data to support claim. Uses some symbology.	Provides appropriate and sufficient evidence to support claim --- Provides multiple GIS data sources showing higher fuel concentration through appropriate symbology
Reasoning A justification that links the claim and evidence and shows why the data counts as evidence to support the claim by using the appropriate and sufficient principles	Does not provide reasoning or only provides reasoning that does not link evidence to claim --- No relationship between fuel load and fire intensity is given	Provides reasoning that links the claim and evidence. Repeats the evidence and/or includes some scientific principles but not sufficient. --- Explains how fuel load contributes to fire intensity (“The larger symbols show areas with larger concentrations of 1000 hr downed wood which would provide the fire much fuel to burn”)	Provides reasoning that links evidence to claim. Includes appropriate and sufficient scientific principles. --- Explains the difference between each fuel type and how it would impact the intensity of the fire. (“Litter as shown in the green symbols provides little fuel for fires to burn. Howevever, ….”)

Management Choices

Students will describe why fire is a greater danger today since our policy of fire suppression has started. Students will the negative impacts of fire on a environmental communities and human communities. They will then propose management choices to reduce or eliminate the impact of fire on human populations and ecosystems.

		Level	
Component	**Unsatisfactory (Below Performance Standard)**	**Proficient (Acceptable)**	**Advanced (Demonstrates exceptional performance)**
Science and Social Perspectives	Does not explain why fire is a greater danger today Does not describe fire's impacts on the environment or the human populations	Lists human activities that have contributed to fire. Lists some of fires impacts	Assesses the reasons for fire danger today in relation to US Fire policy current and historical and the impacts of fire on both humans and the environment.
Claim: An assertion or conclusion that answers the original question	Does not make a claim or makes an inaccurate claim --- *Polygon drawn around an area not investigated.*	Makes an accurate but incomplete claim --- NA	Makes and accurate and complete claim --- *Identifies areas to be managed and management method to be used using GIS tools. (Draw a polygon around the area to be targeted and note that it will be thinned using non-fire treatment)*
Evidence: Scientific data that supports the clai. The data needs to be appropriate and sufficient to support the claim	Does not provide evidence or only provides inappropriate evidence. (Evidence that does not support claim) --- No evidence or inaccurate mapping in ArcGIS	Provides appropriate but insufficient evidence to support claim. May include some inappropriate evidence --- *Uses at least one source of evidence collected and GIS data to support claim. ("Non-fire treatment should be used because the fuel load here is …")*	Provides appropriate and sufficient evidence to support claim --- *Uses multiple sources of evidence collected and GIS data to support claim. ("Non-fire treatment should be used because the fuel load here is … and the slope is … and there is little human habitation in the area")*
Reasoning A justification that links the claim and evidence and shows why the data counts as evidence to support the claim by using the appropriate and sufficient principles	Does not provide reasoning or only provides reasoning that does not link evidence to claim --- *Analyzes the costs, benefits and risks associated with proposed management method. ("Hand thinning such as …. would be the best because its cheaper)*	Provides reasoning that links the claim and evidence. Repeats the evidence and/or includes some scientific principles but not sufficient. --- *Limited reasoning without looking at costs, benefits and risks associated with proposed management method. ("Prescribed fire would be better because it would get rid of the fuel load")*	Provides reasoning that links evidence to claim. Includes appropriate and sufficient scientific principles. --- *Analyzes the costs, benefits and risks associated with proposed management method. ("Hand thinning such as …. would be the best because A – B- C – ")*

Wallow Fire Map – June 15



The newly burned land left in the wake of the Wallow Fire is dark red in this false-color image taken on June 15, 2011. The image, acquired by the Landsat 5 satellite, is made with infrared light. The slightly blue blur is smoke, and dots of bright orange-red on the south side of the burn are active fires. Unburned forest is green, and sparsely vegetated land is pink.

By the end of the day on June 15, the Wallow Fire had burned 487,016 acres of forest in eastern Arizona and was 20 percent contained. Most of the fire activity was on the south side of the fire, away from the majority of the communities that had been evacuated. Among the places evacuated were Greer and Eager, labeled in the image. Irrigated plants (like lawns) are pale spots of green and buildings are tiny dots of blue. Most of the 32 homes destroyed in the fire were in Greer, where the fire clearly burned to the edge of the community. While the burned area encroaches on Eager in places, a buffer of green separates the community from the fire

Basic Information

Incident Type	Wildfire
Cause	Under Investigation
Date of Origin	Sunday May 29th, 2011 approx. 01:30 PM
Location	Eastern AZ near Alpine, Nutrioso, and Springerville
Incident Commander	Area Commander Jim Loach

Current Situation

Total Personnel	2,846
Size	534,639 acres
Percent Contained	67%
Fuels Involved	10 Timber (litter and understory)
Fire Behavior	Zone 1: Small islands of interior heat became active after sun up and produced short runs in stringers of interior fuels. Smoldering 1000 hr fuels are being totally consumed by fire. Zone 2: Aggressive backing and flanking fire on the south perimeter with frequent torching. Zone 3: Backing and flanking with single tree torching.
Significant Events	Zone 1: Community meeting in the City of Springerville. Zone 2: Pincha-Tulley IMT1 assumed command at 0600 today, June 23rd. Resources held the fire north of Blue River drainage. Resources made good progress constructing dozer line from HWY 191 toward the Primitive Area boundary in the Strayhorse drainage area. Zone 3: Continue mop-up, patrol, and rehab.

Outlook

Planned Actions	Zone 1: Mop-up and secure firelines while providing for point protection as needed. Rehab will continue including chipping along roads and seeding dozer lines. Zone 2: Structure protection in Luna, Alpine, and Blue River area. Strengthen, secure, and burn out prepared lines. Continue indirect line and prepare for burn out east of HWY 191 in the Strayhorse drainage. Zone 3: Continue mop-up, patrol, and rehab in all areas.
Growth Potential	High
Terrain Difficulty	High
Remarks	Zone 1: Two injuries occurred over the last two days but were determined today to be lost time incidents this morning. Will continue demobilization of excess resources. Zone 2: One injury reported was non-traumatic and is pending diagnosis. Contingency planning is in progress to address concerns on the southern portion of the fire. Zone 3: None.

Current Weather

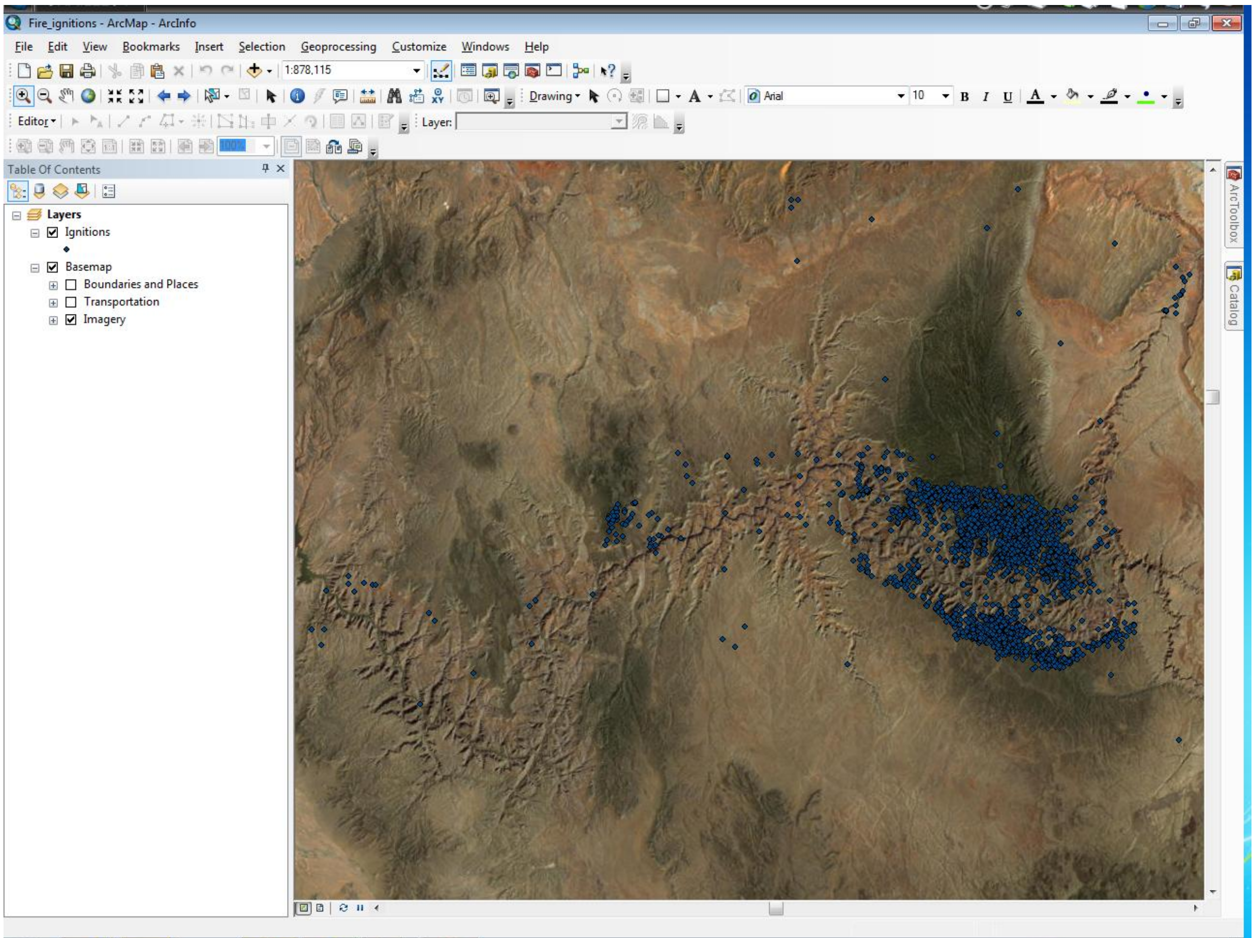
Wind Conditions	19-31 mph SW
Temperature	85-97 degrees

Ignition Map

Students will copy the ignition layer.

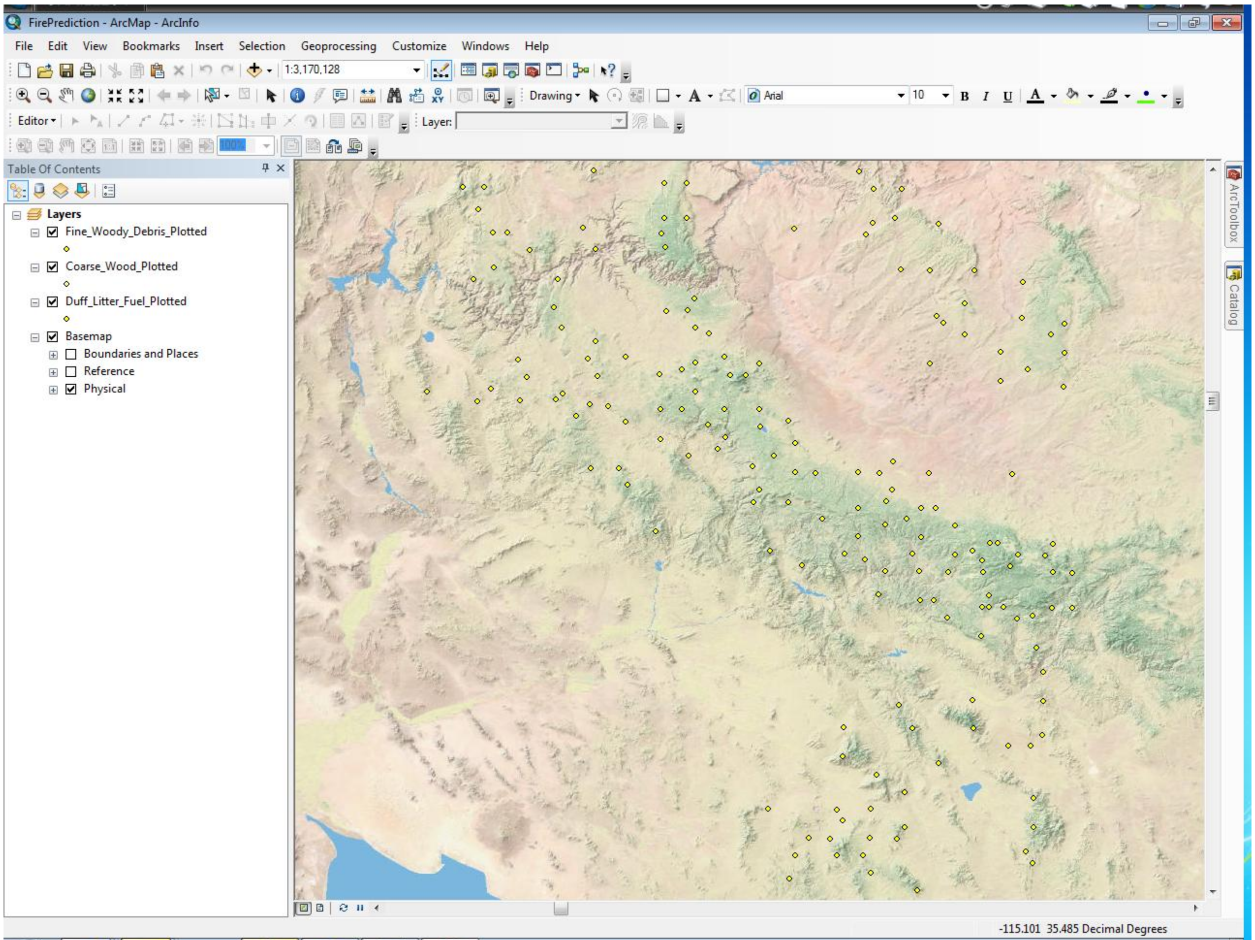
They will symbolize the layer initially based on source (M-L)

The will also symbolize it based on fire size.

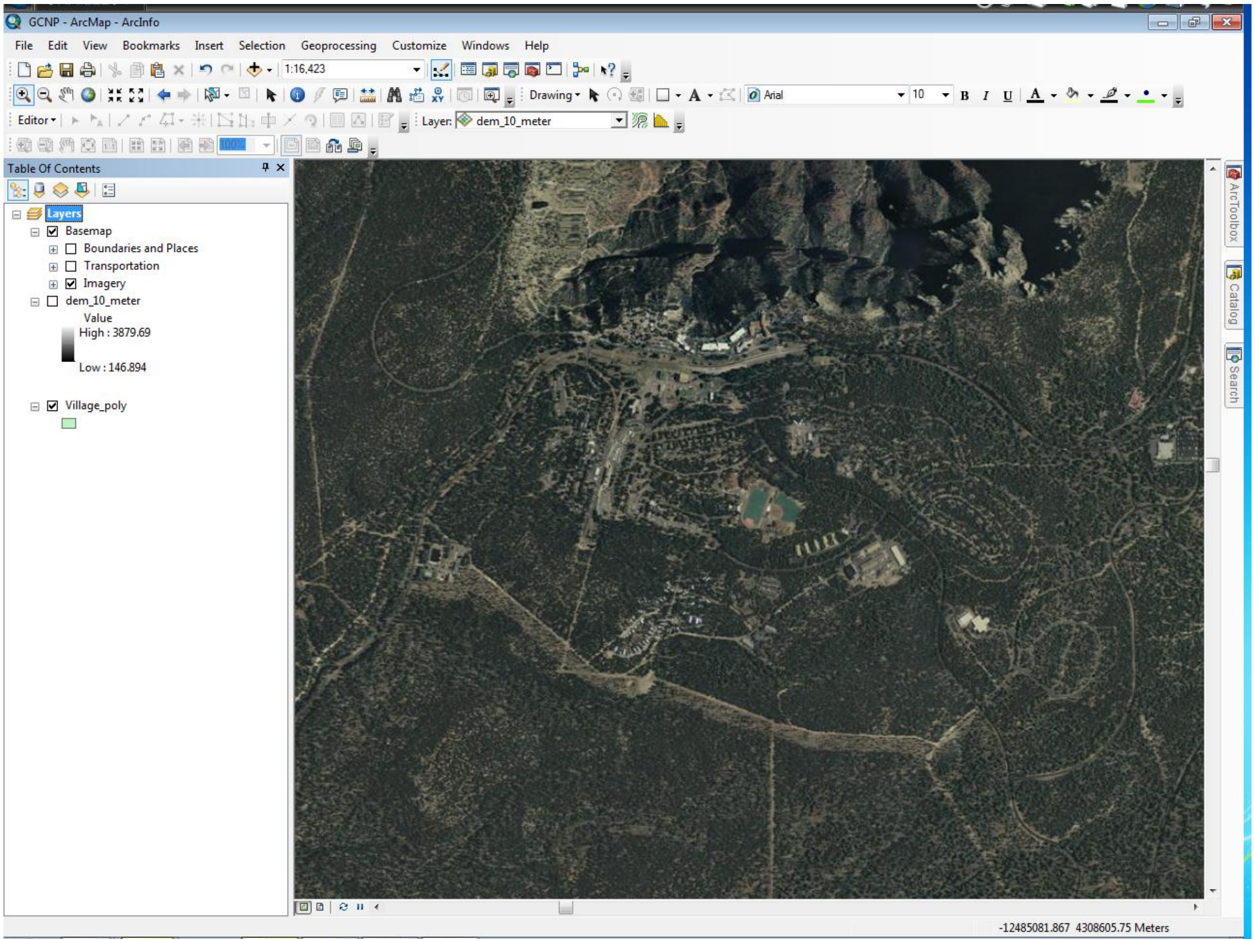


Fire Prediction Map

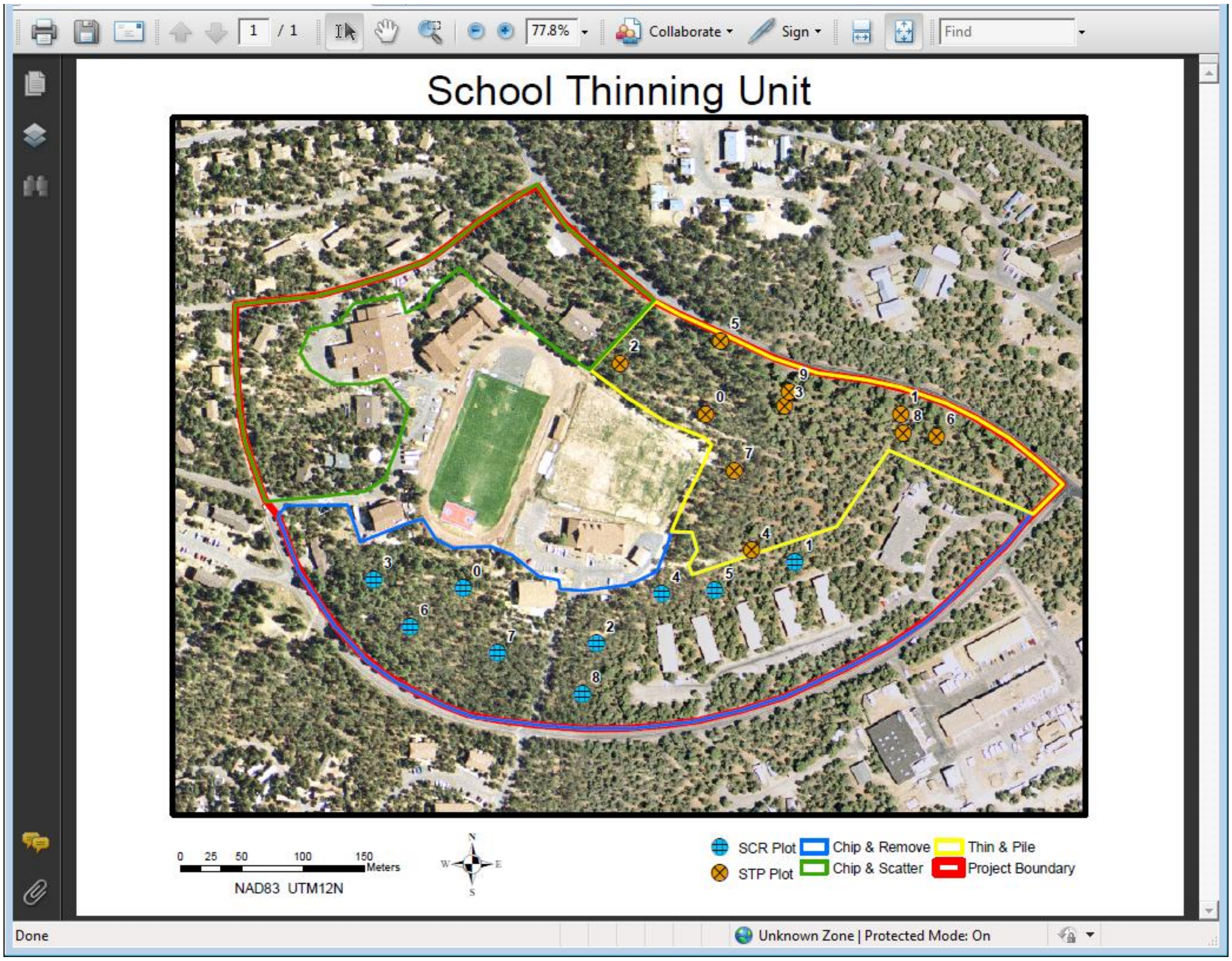
Students will symbolize each layer based on attributes of the layer. Data attribute documentation is at http://fia.fs.fed.us/library/database-documentation/ (Phase 3)



Grand Canyon Fire Analysis



Map provided by NPS with data points


Collaborate
Sign
Find
School Thinning Unit
SCR Plot
STP Plot
Chip & Remove
Chip & Scatter
Thin & Pile
Project Boundary
0 25 50 100 150 Meters
NAD83 UTM12N
Done
Unknown Zone | Protected Mode: On

Project Planning Form – Local Water Resource Analysis

Begin with the End in Mind

- Water distribution and cycling on Earth
- Human use of and impact on water
- Colorado distribution of surface and subsurface water supplies, related to population
- Local County water sources and population impact

Identify the content standards that students will learn in this project

Colorado Earth Science Content Standards – High School: There are costs, benefits, and consequences of exploration, development, and consumption of renewable and nonrenewable resources.

Evidence Outcomes – Students can:

a. Develop, communicate, and justify an evidence-based scientific explanation regarding the costs and benefits of exploration, development, and consumption of renewable and nonrenewable resources
b. Evaluate positive and negative impacts on the geosphere, atmosphere, hydrosphere, and biosphere in regards to resource use
c. Create a plan to reduce environmental impacts due to resource consumption
d. Analyze and interpret data about the effect of resource consumption and development on resource reserves to draw conclusions about sustainable use

National Science Education Standards – Science in Personal and Social Perspectives: Content Standard F, grades 9-12, Specifically:

a. Populations can reach limits to growth. Carrying capacity is the maximum number of individuals that can be supported in a given environment. The limitation is not the availability of space, but the number of people in relation to resources and the capacity of Earth systems to support human beings.
b. Human populations use resources in the environment in order to maintain and improve their existence. Natural resources have been and will continue to be used to maintain human populations.
c. The earth does not have infinite resources; increasing human consumption places severe stress on the natural processes that renew some resources, and it depletes those resources that cannot be renewed.
d. Natural ecosystems provide an array of basic processes that affect humans. Those processes include maintenance of the quality of the atmosphere, generation of soils,

control of the hydrologic cycle, disposal of wastes, and recycling of nutrients. Humans are changing many of these basic processes, and the changes may be detrimental to humans.

Craft the Driving Question

Where does your water come from, how is it used, and can current population growth trends continue while maintaining a sustainable water supply?

Performance Objectives/Targets-

Early:

By modeling water distribution on Earth and graphing the results, students will illustrate how a finite water supply on Earth is distributed Among different sources (graph and summary statement)

By following the many routes of a water molecule through a complex branching water cycle (Hydro), students will organize the various sources and sinks of water in the cycle and create a schematic (poster, graphic, Inspiration web) of the sources and sinks

Through Internet research, students will evaluate the many human uses of water and the possible disruptions of water availability or quality that result from each use (written document, poster, or PowerPoint)

During:

Using GIS, students will calculate surface water availability per capita in the state of Colorado and analyze the visualization. Based on this analysis, they will assess possible conflicts due to different human uses for the water and availability throughout the state. (Map of surface water riverflow data; map of population; map of land use; map of surface water per person; written document, poster, or powerpoint for analysis summary)

End:

Through their research and analysis, students will determine the source(s) and uses of their local water supply. Based on understanding of current population growth trends in the area, they will compile possible threats to their water quality and quantity and propose community action to protect a sustainable water supply.

Plan the Assessment

Step 1: Define the products and artifacts for the project:

Early in the Project:

Water Sources – Graph and Summary Statement comparing predicted and actual % of total water stored in different water sources.

Water Cycle- Inspiration Water Web detailing sources and sinks in complex water cycle

Water use and population impacts – Option: Essay, Poster, Powerpoint

During the Project:

GIS Products – 3 Layouts detailing water availability, population, and water availability per person – Option: Poster or Powerpoint

End of Project:

Presentation of recommendation to the community – Visual Display and Oral Presentation, including source(s) of local water, uses of local water, local population trends, threats to water supplies, proposal for community action to protect a sustainable water supply.

Map the Project

Product: PowerPoint or Poster, including GIS layouts, summary compilations, recommendations

Knowledge and Skills Needed	**Already**	**Before**	**During**
Know water distribution on Earth		X	
Know complex water cycle		X	
Have Internet research skills	X		
Know ArcMap skills		X	X
• Add data		X	X
• Perform math operation on data		X	X
• Selection criteria		X	X
• Display decisions		X	X
• Produce layouts		X	X
Know local water source(s) and population			X
Presentation skills	X		

Map the Project:

Week 1	Where is the water activity	Hydro Water Cycle Webbing Activity	Research Water Use and Population Impacts	
Week 2	GIS-Introduction using state riverflow data and population as context	Adding data, basic operations, math operations	Selection and display options, Layouts	Form groups Set project expectations
Week 3	Research local water sources, use, population growth statistics	Group work on final project	Group work on final project	Presentations- Gallery tour (Peer and others review)

Rubric Template:

Component	Level 0	Level 1	Level 2
Claim- An assertion or conclusion that answers the original question.	Does not make a claim, or makes an inaccurate claim.	Makes an accurate but incomplete claim.	Makes an accurate and complete claim.
Evidence- Scientific data that supports the claim. The data needs to be appropriate and sufficient to support the claim.	Does not provide evidence, or only provides inappropriate evidence (Evidence that does not support the claim.	Provides appropriate, but insufficient evidence to support claim. May include some inappropriate evidence.	Provides appropriate and sufficient evidence to support the claim.
Reasoning- A justification that links the claim and evidence and shows why the data counts as evidence to support the claim by using appropriate and sufficient scientific principles.	Does not provide reasoning, or only provides reasoning that does not link evidence to claim.	Provides reasoning that links the claim and evidence. Repeats the evidence and/or includes some scientific principles, but not sufficient.	Provides reasoning that links evidence to claim. Includes appropriate and sufficient scientific principles.

Plan the Assessment:

Step 2: State the criteria for exemplary performance for each product:

Product:	Graph of Global Water Distribution
Criteria:	Using scoring rubric: Data correct and complete Axes labeled and scaled correctly Quality Criteria (neat, color-coded)
Product:	Water Web or Graphic
Criteria:	Rich display of sources and sinks , specify # of each required Quality Criteria (neat, pleasing) Demonstrates complexity of cycle (vs. simple single cycle)
Product:	Poster/PowerPoint
Criteria:	Specify x # human uses, with matching impacts Extension into specific uses/impacts of local water Summary based on evidence gathered Source documentation and references (#) Quality Criteria
Product:	GIS Products Presented in Poster/PowerPoint
Criteria:	4 layouts Quality Criteria: correct, well-organized, visually pleasing Description of potential conflicts and consequences # based on data and analysis Quality Criteria
Product:	Poster or PowerPoint or……
Criteria:	Content: Correct results of research Water sources ID'd Human Uses ID'd source documentation and references (#) Population Growth Projections Description of threats to quality and quantity # based on data and analysis GIS Visualization and Presentation

Layout(s) including required data
Display of Summary Points
- #
- based on data and analysis

Proposal for Community Action
- #
- based on data and analysis

Presentation Quality Criteria

Appendix E
Semi-Structured Interview Protocol

Background with technology integration

Briefly describe the technology you have taught with:

Briefly describe the technology you have had students use in your classes:

Context

Briefly describe the school environment in which you work:

How much flexibility are you allowed within your curriculum?

Implementation

1. Provide specific examples of what (if anything) from the PD you have implemented in your classes.

(Based on response, use the following probes:)

a. Lessons from PD: Mapping our World, landforms, graham cracker lab, etc.
b. Own lessons
c. Projects based on “real-world problems”
d. Claims and evidence
e. Use of geospatial technologies, Labquests etc.
f. CTS
g. FACTS/rubrics/summative assessments

(Based on response, probe): Which classes are you implementing these technologies/strategies in?

2. Identifying one example, what was the reason for implementing this specific lesson/ activity/strategy?

3. What type of support did you have as you implemented the lesson/activity/strategy?

4. What went well in the lesson? What would you do differently?

(Probes: technology challenges, student response to the lesson, etc.)

5. Was the lesson/activity effective for student learning? What is your evidence for this?
    1. What areas of student learning are you referring to (subject matter, communication skills, technology skills, data analysis skills)?

6. Was the lesson/activity/instructional strategy effective for student engagement in the subject matter? What is your evidence for this?

7. How did you assess student learning in this lesson/activity?

8. If you have taught this lesson before, do you think GIS helped, hindered or had no effect on student learning?

Barriers

9. If you encountered obstacles attempting to implement lessons/activities from the PD, how did you overcome them?

10. Where there any barriers that prevented you from teaching these lessons/activities/strategies?

11. What computer resources do you have available at your school?

    a. Do you have reliable access to the computer lab?
    b. Has a computer support person been available, helpful?

12. Are there any things at the local/school/state levels that influence the use of geospatial technology in teaching? What are some examples of this?

Impacts

13. Have you participated in other geospatial activities/professional development because of this experience?

    a. Have you mentored other teachers at your school in the use of geospatial technology?

14. Have your conceptions changed about the role of geospatial technologies in the classroom? Explain based on your experiences.

15. As a result of your implementation of the PD, was there any impact on student interest in STEM/geospatial careers? Please elaborate with specific examples.

Future

16. Do you plan to continue teaching with geospatial technologies in the future? Why or why not?

17. What additional support, if any, would help you continue to teach with geospatial technologies?

18. Do you plan to continue teaching with other strategies (PBI etc.) in the future? Why or why not?

Appendix F
Data Analysis and Emergent Codes

Coding Category	Coding Criteria	High	Medium	Low	None
Teaching Actions	1. Opportunities for students to engage in authentic projects 2. Opportunities for students to collect and analyze data 3. Opportunities for students to work with and/or present findings to local stakeholders and professionals 4. Opportunities for students to use GST to learn content and communicate ideas during observations	All 4 criteria were met	3 of these criteria were met	2-1 of these criteria were met	0 of these criteria were met
Beliefs about Teaching and Learning	1. Student-centered approaches 2. High outcome expectancy for students 3. Importance of making learning relevant 4. Data collection and analysis opportunities for students 5. Engaging community members in student learning 6. Recognition of GST as a tool for student learning and communication instead of a learning goal in itself	4 or more of these criteria were met	3 of these criteria were met	2-1 of these criteria were met	0 of these criteria were met
Teaching Context	1. Manageable class size 2. Flexibility in subject matter and curricular decisions 3. Access to reliable technology 4. Extended time to work on projects 5. Administrative support 6. IT support 7. Teaching supports	5 or more of these criteria were met	4-3 of these criteria were met	2-1 of these criteria were met	0 of these criteria were met
Technology Ability	1. Level 0 = Inability to use the map or data to obtain information to answer the question. 2. Level 1 = Able to use the map and/or data to obtain information to answer the question. 3. Level 2 = Able to use the map and/or data to obtain information to answer the question and to create a basic	Level 3 or Level 4	Level 2	Level 1	Level 0

	map adding points, lines and polygons to the map to represent geographic features. 4. Level 3 = Able to use the map and/or data to obtain information to answer the question and create a basic map, add points, lines and polygons to the map to represent geographic features and symbolize geographic features based on levels of variability in data across a region (choropleth map). 5. Level 4 = Able to use the map and/or data to obtain information to answer the question and create a basic map, add points, lines and polygons to the map to represent geographic features, symbolize geographic features based on levels of variability in data across a region (choropleth map) and create a layout with a graphic (bar graph or pie chart) and/or include other graphical representations to communicate ideas.				

Appendix G

Macroinvertebrate Lesson

Why is there a difference between the macroinvertebrate population at [omitted] Park and the [omitted] Trail sites located along [omitted] Creek?

I. Subject Area

Chemistry

II. National Standards

a. Content Standard F: Science in Personal and Social Perspectives
   Environmental Quality:
   i. Natural ecosystems provide an array of basic processes that affect humans. . . Humans are changing many of these basic processes, and the changes may be detrimental to humans.
   ii. Materials from human societies affect both physical and chemical cycles of the earth.

b. Content Standard B: Physical Science
   Chemical Reactions:
   i. Chemical reactions occur all around us, for example in healthcare, cooking, cosmetics, and automobiles. Complex chemical reactions involving carbon-based molecules take place constantly in every cell in our body.

II. State Standards

a. Strand 3, Concept 1, PO 2 Describe the environmental effects of the following natural and/or human-caused hazards: pollution
b. Strand 3, Concept 1, PO4 Evaluate the following factors that affect the quality of the environment: urban development
c. Strand 5, Concept 4, PO11 Predict the effect of various factors (e.g., temperature, concentration, pressure, catalyst) on the equilibrium state and on the rates of chemical reaction.
d. Strand 5, Concept 1 PO 2 Describe substances based on their chemical properties.

III. Key Skills

a. Information: Acquire and evaluate data

b. Computing: Use computers to process information

c. Critical thinking and doing: problem solving, research, analysis, project management.

d. Communication: Use media effectively to communicate results

IV. Habits of Mind

- Questioning and posing problems

V. Lessons

a. Launch – review previous data collected and conclusions

b. Research Environmental Variables

c. Create Poster with key findings from research paper

d. How to use Labquests

e. Analyzing Data using ArcMap – [omitted] Fire Exercise

f. Write procedure for data collection

g. Collect Data on Variable

h. Adding Data to ArcMap

i. Analyze Data and Form Conclusions

j. Power point presentation

VI. Statement of Problem

Human practices can affect factors critical to the health of ecosystems. These practices include but are not limited to development, farming, mining, water usage and recreation. Do the communities of [omitted] affect the ecosystem of [omitted] Creek? So far we have discovered that macroinvertebrates, biological indicators of ecosystems, have a smaller and less diverse population near [a park and] another site along [omitted] Creek located outside of town.

Why is the macroinvertebrate population at [omitted] Park smaller and less diverse than other areas along [omitted] Creek?

VII. Performance Objectives

a. Students will research how their assigned environmental variable affects ecosystems using classroom and online resources.

b. Students will create a poster displaying key findings from their research paper.

c. Students will write a procedure on how they will collect data.

d. Students will collect and organize data on their assigned environmental variable using a Labquest.

e. Students will produce a map with data they collected using ArcMap.

f. Students will form a conclusion based on their research and data analysis on why there is a difference in the macroinvertebrate population [between two sites].

g. Students will present their maps and their findings using a Power Point presentation.

VIII. Map the Project

Knowledge and skills needed	Already have learned	Taught before proj.	Taught during proj.
1. Navigating GIS (basic)	X	X	
2. Ecosystems	X		
3. Geochemical Cycles		X	
4. Elements & Compounds		X	
5. Chemical Reactions		X	
6. Environmental Pollutants		X	
7. Research and gathering information			X
8. How to use Labquests	X		X
9. Testing water samples/ collecting data in the field			X
10. Adding data to ArcMap	X	X	X
11. Analyzing data/looking for patterns			X
12. Making a claim and presenting it			X

IX. Implementation Schedule of Lessons

- Week 1
    - Day 1: Launch - Review last year's data and results, handout project outline
    - Day 2: Variables are assigned. Bibliography tips. Students begin research.
    - Day 3 & 4: Research Papers. Teacher goes over how to use a Labquest with individual students.

- Week 2
    - Day 1: Students make a poster listing key findings about their variable to share with the class. Students take notes on the posters.
    - Day 2: Students organize materials needed for data collection. Students write out their procedure for data collection.
    - Day 3 & 4: Field Trips to Creek to collect data. Data is put into a spreadsheet.
- Week 3
    - Day 1: How to analyze data using ArcMap –Fire Exercise
    - Day 2: Computer Lab – Students begin making their maps, adding data and organizing it with teacher guidance. Adding Data directions
    - Day 3 & 4: Students work on finishing their maps and making power points.
- Week 4 -5
    - Day 1: Finish up Power point and add map to power point. How to Save map as a jpeg
    - Day 2 & 3: Make power point presentation

X. Manage the Process/Differentiated Instruction

Lessons will be delivered using various teaching techniques that cater to different learning styles. These include but are not limited to use of visual aids, modeling, and guided practice.

XI. Procedure Students will Follow to Create Deliverables

a. Write a research paper on assigned environmental variable (chemical pollutant)

b. Create a poster with key findings on assigned variable to share with other students. Take notes on other posters so you have some background on other variables when making claims.

c. Write a procedure for collecting data in the field

d. obtain data on assigned environmental variable from the field using test kits and Labquests

e. add data to excel spreadsheet , teacher adds data to geodatabase

f. add data from geodatabase to ArcMap

g. add field collected data to ArcMap

h. conduct analysis

i. form conclusions

j. create presentation that includes research, findings (maps)and conclusion

XII. Data Collection

a. Data – Student Collected variables

i. Water pH

ii. Phosphate concentration

iii. Nitrate concentration

iv. N:P ratio

v. Dissolved oxygen

vi. BOD (biochemical oxygen demand)

vii. Temperature

viii. Turbidity

ix. Depth

x. Hardness

xi. Copper

xii. chlorine

xiii. fish/crayfish

b. Data – Online sources

i. Aerial Imagery

ii. Public

iii. Landcover

iv. Slope

v. Hillshade

vi. Golf courses

vii. Farms

viii. Pavement

ix. drainage

XIII. Analysis/Evaluation

Creek Analysis Using GIS

	4. Distinguished	3. Proficient	2. Apprentice	1. Novice
Lab Work-Data Quality: Accurate measurement and labeling (Excel Spreadsheet)	All data was complete and accurately labeled. Data was preprocessed correctly for GIS.	All data was complete and accurately labeled. Attempted to preprocess data for GIS.	Data was incomplete. Some data was not labeled using appropriate units of measure. Data was not preprocessed for GIS.	Included little or no relevant data. Data was not preprocessed using GIS.
Lab Work-Data Display: Data is displayed using graphs, charts, and tables (Map)	Pertinent data was added correctly to an ArcMap document. Features/layers are labeled and easy to distinguish from one another.	Pertinent data was added correctly to an ArcMap document. Features/layers are labeled.	Unpertinent data was added correctly to an ArcMap document. Features/layers are labeled.	Data was not added correctly to an ArcMap document or data is missing. Features/layers are not labeled.
Lab Work-Data Analysis: Student analyzed data and identified trends (Final Assessment Power Point)	Identified and described patterns. Made appropriate conclusions based on the data. Used ArcMap document to support conclusion.	Identified and described patterns. Made conclusions based on the data. Limited use of ArcMap document to support conclusion.	Only identified obvious patterns or found patterns not fully supported by the data. Limited use of ArcMap document to support conclusion.	Patterns were missing or were not supported by the data collected. Obvious patterns were overlooked.
Research-Overview: Quantity, quality,	Paper is at least one page in length and clearly describes topic. Project	Paper is at least one page in length and clearly describes topic. Project	Paper is less than one page in length or vaguely describes topic. Project	Paper is less than one page in length or vaguely describes topic. Bibliography or

and documentation (Research Paper)	bibliography or credits were complete.	bibliography or credits were missing or incomplete.	bibliography or credits were complete.	credits were missing or incomplete.

XIV. Deliverables

a. .mxd (ArcMap document)

b. PowerPoint Presentation

Appendix H

Weather and Climate Lesson Plan

Narrative:

Weather and climate is the theme for the STEM 1 course. All subjects and projects are related to this theme.

Some Topics and Themes (All have math associated)

Atmospheric Wind Currents (physical Science)

Ocean Currents (physical Science)

Coriolis Effect (physical Science)

Global Warming (physical Science)

Ocean Acidification (chemistry)

Sea Level Rise ((physical Science)

Storm Surges (physical Science)

El Niño & La Niña (physical Science & biology)

Lesson Observed (videotaped)

This lesson is a continuation in the impacts associated with climate change. The focus was storm surges and their impacts on coastal communities. The class had just finished World 2, Modules 7, and Lesson 1 – Sea Level Rise. Their final assessment in that lesson was to create a short and long term plan for a city that would adversely be affected by a significant increase in sea level. They researched and documented the impacts on the population and tried to plan for predicted events. Finding timelines for sea level rise was problematic and the models projecting the future are not credible given the lack of data available on the loss of land-based glaciers.

This was a perfect opportunity to look at circumstances that are more immediate and dire in nature – the storm surges caused by hurricanes. Hurricanes are the topic for lesson 2 so this seemed to be a logical segue into the impacts associated with hurricanes. As with lesson 1 and the focus on at-risk communities, lesson 2 also looks at at-risk but from a weather event, not a change related directly to climate change.

The PowerPoint used will be sent along with this document.

Beginning of lesson: It was time for the students to reflect on the definitions of weather and climate. We added to that the attempt to connect the dots between seal level rise and these two. The final question dealt with whether the two could be connected – “Do you think that changes in climate may cause changes in the weather?”

Storm Surge: The concept of "storm surge" was introduced to the class. Since coastal destruction was fresh in their minds, it was a natural to show the impact of large storm surge in real situations. The hope was that this would show the devastation that might be associated with sea level rise.

ArcGIS: After the presentation the class was divided in half. The group that stayed with me went over the objectives of Module 2, Lesson 1. We then moved into the computer lab to begin a three-day lesson. The students are working in groups of two or three – each having a computer. In the groups with two students one computer will have the ArcMap and the second will have the directions (only the answer sheet is printed).

We spent two days in the computer lab and then I showed the video *The Fire Below Us* which is a documentary about the eruption of Mount Saint Helens. The video shows the eruption and consequential mud flows as a result of the flash melting of the glaciers on the mountain. The devastation was wide spread and gave the students an opportunity to visualize what might happen to a population center near a volcano or mountain after severe weather events – such as a hurricane – Mitch in 1998 in particular.

A supplemental article was also provided with questions concerning changes in technology (see attachment).

ArcGIS – World 2, Module 7, and Lesson 2 is a very adaptable lesson. I chose to have the students work in small groups (2 or 3 students in a group). Each student had their own computer to work on but one would open the ArcMap and the other student(s) would have the directions open. Note: To save paper we put the instruction files on our server so that students could access them easily. Prior to Module 7 students had to do independent work and could split their screens to view both.

The result of the student work is submitted for this project. Students were not required to submit maps with their assessments but some decided to do so.

The ArcGIS modules provide a comprehensive lesson. It is used in our STEM 1 curriculum. We believe that the "silo" method of teaching does not provide the best type of learning environment for our students. The areas that the ArcGIS lessons touch on are as follows:

> *World Geography*: This greatly enhances our approach to the weather and climate focus. Our students do not get geography in any applied manner.
>
> *Technical Readin*g: Even though our students receive reading instruction from first grade they have not been exposed to the type of detailed, technical reading that they are required to do in the ArcGIS lessons. Many struggle with following written directions. It is a battle to constantly reinforce the point that they have to read and comprehend before they are successful.
>
> *Research and Technical Writing:* The new common core standards require students to be proficient in technical, and non-fiction reading and writing. There are virtually no classes

currently that address these requirements. The social studies department is becoming more aware of these requirements bust as of yet has not complied. The ArcGIS lessons require students to look at data and develop plans and approaches to problems that are real or perceived (see student assessments in materials sent).

Collaborative Work: Once again students do not really work in collaborative environments. The STEM courses are 90% collaborative and the rest individual. The world of work is very much the same ratio.

Assessments: Our assessments are nearly all authentic in nature. That means that we do not given "multiple guess" tests. Each project has outcomes and students are scored on those outcomes. On large projects that require weeks to complete there are intermediary steps that are assessed.

Math and Science: Every lesson that we teach requires math and science. We teach the math and science the students need when it is appropriate. We do statistical analysis almost with every project because students are collect data and they must use their data to support their claims. Some projects require algebra and geometry. The science could fall into these categories – earth science, physical science, and biology.

Language Arts: Our students are required to write reports and research papers. They are required to make presentations based upon their findings. Everything is integrated and everything is important. The students see the need to be able to read and write in the projects that we choose.

Social Studies: We really don't look for specific historic events, but every project requires that students understand that the past is part of the present and future. We have looked a records of data on carbon dioxide concentrations, seal levels over time, the industrial revolution and its impact, and the students have learned to model from their data collect to look into the future.

Common Core Standards:

Math –

HS.MP.2 Reason abstractly and quantitatively.

S.IC.1 Understand statistics as a process for making inferences about population parameters based on a random sample from that population.

S.IC.2 Decide if a specified model is consistent with results from a given data-generating process.

Science –

9-10.RST.2 Determine the central ideas or conclusions of a text; trace the text's explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text.

9-10.RST.3 Follow precisely a complex multistep procedure when carrying out experiments, taking measurements, or performing technical tasks, attending to special cases or exceptions defined in the text

9-10.RST.8 Assess the extent to which the reasoning and evidence in a text support the author's claim or a recommendation for solving a scientific or technical problem.

9-10.WHST.4 Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.

Attachment:

Mount Saint Helens - Yesterday and Today

October 12, 2004
At Mount St. Helens, the Big Eruption Is of Data, Not Lava
By KENNETH CHANG

When Mount St. Helens was last erupting in the 1980's, Dr. Elliot Endo recalls using a ruler to measure the size of the squiggles on seismographs.

Now he tracks St. Helens with a high-end cellphone. "I look at my plots on a Treo 600, and it's really cool," said Dr. Endo, scientist-in-charge at the United States Geological Survey's Cascades Volcano Observatory in Vancouver, Wash.

Technology developed over the last two decades "has allowed us to do a better job of monitoring and allowed us to interpret the data much more quickly," he said.

It has also made the work safer. Dr. David A. Johnston, a 30-year-old geologist with the geological survey, was one of 57 killed by the eruption of Mount St. Helens on May 18, 1980, because he was at an observation post five miles from the volcano.

Today scientists observe the volcanoes from much greater distances. Global positioning system sensors send signals to orbiting satellites, which triangulate the sensors' locations within a fraction of an inch. Radar from other satellites provides a three-dimensional view of the landscape and detects subtle deformations as magma pushes up from below. Those data fly across the Internet to scientists around the world.

"In 1980, we had to rely on surveying techniques that required people on the ground and clear weather in order to be able to see targets," Dr. William E. Scott, a geological survey scientist, said at a news conference last week. When St. Helens reawakened three weeks ago, scientists were better prepared to analyze the situation. So far, they expect some eruptions, but nothing approaching the 1980 cataclysm.

In 1980, scientists did catch the warning signs of an impending eruption. Swarms of earthquakes and the appearance of a bulge alerted them, and they persuaded officials to close surrounding areas, saving lives. But they were still caught off guard by the ferocity of the eruption, which sent up a cloud of ash that blanketed the Pacific Northwest and carried as far as Oklahoma.

"People decided we better try to work at understanding what's happening inside volcanoes," said Dr. Bernard Chouet of the geological survey's volcano hazards program.

Most volcanoes form at the edges of tectonic plates, where hotter material can rise up from below, although a few, like those in Hawaii, occur in the middle of a plate. Those, most geologists believe, are created by hot plumes of rock rising from the core, melting the underside of the earth's crust.

Whether an erupting volcano explodes, raining ash over a wide region, or less destructively dribbles out lava depends primarily on the amount of water in the molten rock. As the underground molten rock, or magma, moves toward the surface, the water, held in by extreme pressures underground, separates out and turns into the steam. That provides the explosive potential. (Hawaiian volcanoes rarely spew ash. In the plume model, the reason for the smooth flowing lava is that deep magmas contain little water.)

Dr. Chouet, working on St. Helens during smaller eruptions after May 1980, noticed that the seismic signals from earthquakes around volcanoes were different from those from ordinary earthquakes. When an earthquake fault slips, breaking rocks, the seismograph reading is a messy, patternless jumble of squiggle. But around St. Helens, the seismic signal often contained a single characteristic frequency, almost as if the earth were singing a particular note.

Indeed, steam rising up through rock cracks resonates "almost like an organ pipe," Dr. Chouet said. Such resonant earthquakes, particularly if nothing is occurring at the surface, indicates pressures are building, he said.

Dr. Chouet said that in the current volcanic episode at St. Helens, the seismic signals of the initial earthquakes, which started Sept. 23, looked like just the breaking of rocks. About four or five days later, the resonant signal appeared. The first steam and ash eruption occurred Oct. 1.

To get a better idea of the plumbing below some of the world's most worrisome volcanoes, scientists have made what are essentially sonograms of the earth. At Mount Vesuvius in Italy, scientists set off a series of small explosions around the mountain and then precisely measured the seismic signals. The carefully monitored mountain has been quiet of late, but the data showed a large magma chamber exists about six miles below the mountain.

"This is quite large," said Marcello Martini of the National Institute of Geophysics and Volcanology in Naples. "The problem is we don't know how deep this goes. We know the top level of this magma chamber."

A similar underground image created for Mount Kilauea in Hawaii showed a complex network of fractures carrying the magma to the surface. While most textbooks depict a single chamber of magma underground with a large conduit leading to a volcano's crater, "We're finding there is no such thing," Dr. Chouet said. "It's going to be much richer than the simple picture you see in textbooks."

Technology for measuring volcanic gases has also improved. The amount of steam rising out of a crater does not tell by itself much about the explosive potential of the magma below because the steam could have come from water percolating down from above and boiling when it hit the magma. Accompanying water in magma, however, are three other gases: carbon dioxide, hydrogen sulfide and sulfur dioxide.

In 1980, scientists could detect only sulfur dioxide, but sulfur dioxide dissolves in water, and that could lead to misleadingly low measurements. Now instruments exist to measure all three.

Even precise gas measurements are not enough to predict the explosiveness of an eruption. Dr. Michael Manga, a professor of earth and planetary science at the University of California at Berkeley, said identical gas-rich magma coming out of the same volcano would not always produce the same eruption. "Sometimes it explodes, and sometimes it doesn't," he said. "How you get gases out of a volcano is an interesting question. You would think after hundreds of years of studying volcanoes, we'd have that answer. But we don't."

So a member of his research group, Dr. Atsuko Namiki, built a volcano in the basement at Berkeley to help provide answers. Instead of red-hot magma, the model volcano erupts gooey xanthan gum, a food additive used as a thickener in pudding, fruit fillings and chewing gum. "We want to do this at room temperature," Dr. Manga said.

Dissolving the gum in water and infusing it with bubbles, Dr. Namiki videotaped the behavior of the gum when the surrounding pressure was suddenly released. That simulates what happens to magma as it rises toward the surface.

To erupt explosively, the magma must break into pieces. On the other hand, if all the gas escapes before the magma reaches the surface, there is no force left to throw the magma into the air. "We can vary all these parameters and conditions in the lab," Dr. Manga said. "We can use models to extrapolate to real volcanoes."

In 1980, a magnitude 5.2 earthquake on the morning of May 18 caused the bulge on the northern flank of Mount St. Helens to slide away. That uncovered the highly pressurized magma below, like popping a cork from a Champagne bottle.

The analogous xanthan gum lava also exploded. "Our lab experiments are at least consistent with Mount St Helens," Dr. Manga said.

Questions:

1) What determines if a volcano will erupt with and explosion (like in 1980) or just ooze (like in Hawaii)?

2) How has advances in technology made it safer to study active volcanoes?

3) How has the advancement in technology allowed scientists to do a better job in evaluation and prediction?

4) How has advances in technology made it possible to share information around the world in "real time"?