An Integrated Field-Based Approach to Building Teachers' Geoscience Skills

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ABSTRACT

The Paleo Exploration Project was a professional development program for K–12 teachers from rural eastern Montana. The curriculum was designed to incorporate geospatial technologies, including Global Positioning Systems (GPS), Geographic Information Systems (GIS), and total station laser surveying, with authentic field experiences in geology and paleontology in an effort to enhance teachers' abilities to incorporate geospatial technologies and inquiry-based approaches into their classrooms. The program included preparatory weekend workshops for teachers and week-long summer research institutes for teachers and students, in which core geosciences skills were practiced in the field. These skills included (1) geology-related spatial visualization, (2) understanding absolute geologic time, including the concepts of physical and temporal correlation of stratigraphic units, (3) actualistic thinking, or the ability to interpret ancient environments through comparison with modern ones, (4) geological field strategies and techniques, and (5) scientific reasoning. Teachers responded very positively to the program, and nearly all went on to create, implement, and enhance their own technology-embedded, inquiry-based projects with their own students over the following two years. Intense preparation for the field experience, including building teacher content knowledge, technology skills, and field techniques, as well as the field-based approach, combining GIS as a visualization tool with field-based examination of geologic features, metacognitive reflection, and working with students in the field, were considered key elements of the program's success.
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INTRODUCTION

There is an unquestioned national need for improving students' abilities in geosciences (American Geological Institute, 2008). Achieving this goal depends largely on teachers' own competencies. Unfortunately, proficiency in the geosciences involves several discipline specific abilities, and few K–12 teachers have significant training in geoscience.

For example, in contrast to other scientific disciplines, geoscience involves specific types of high-level spatial thinking; conceptualizing geologic time; and actualistic thinking (using current observations to explain past conditions or events). Further, geoscientists must be able to exercise these abilities in real world contexts, and therefore must develop proficiency in the strategies and methodologies involved in geologic fieldwork (King, 2008). As with all sciences, geoscience also involves process skills such as hypothesis formation, identifying appropriate observational evidence, combining multiple lines of evidence, and scientific reasoning.

Spatial thinking is important to many STEM (Science, Technology, Engineering, and Math) disciplines, but geoscientists in particular must have excellent visualization skills. Specifically, they must be able to visualize how three-dimensional (3D) stratigraphic units intersect the Earth's surface, and how these complex structures change through time (King, 2008). Titus and Horsman (2009) described three component skills that are particularly important in geoscience-related visualization (Fig. 1). These include (1) spatial relations, or the ability to mentally rotate objects, (2) spatial manipulation, or the ability to mentally manipulate an image into another arrangement, and (3) visual penetrative ability, or the ability to picture what is inside of a solid object *sensu* (Kali and Orion, 1996).

Although people vary widely in their innate spatial thinking abilities (Lord, 1985; Kali and Orion, 1996; Piburn *et al.*, 2002; Hegarty *et al.*, 2006), many struggle with spatial tasks. In a mock field exercise, Kastens *et al.* (2009) demonstrated that students had problems conceptualizing outcrops as discontinuous fragments of the underlying geologic structure. Instead, many thought of individual outcrops as generalizations of an entire subsurface structure. This and other studies demonstrate that many students have trouble understanding scale relationships between models or representations and the real world and have limited visual penetrative ability (Kali and Orion, 1996).

Fortunately, many studies demonstrate that spatial abilities can be improved through practice, including coursework, working with 3D models, interactive computer models; and field experiences (Lord, 1985; 1987; Orion *et al.*, 1997; Piburn *et al.*, 2002; Sorby, 2001; Kastens *et al.*, 2009; Titus and Horsman, 2009).

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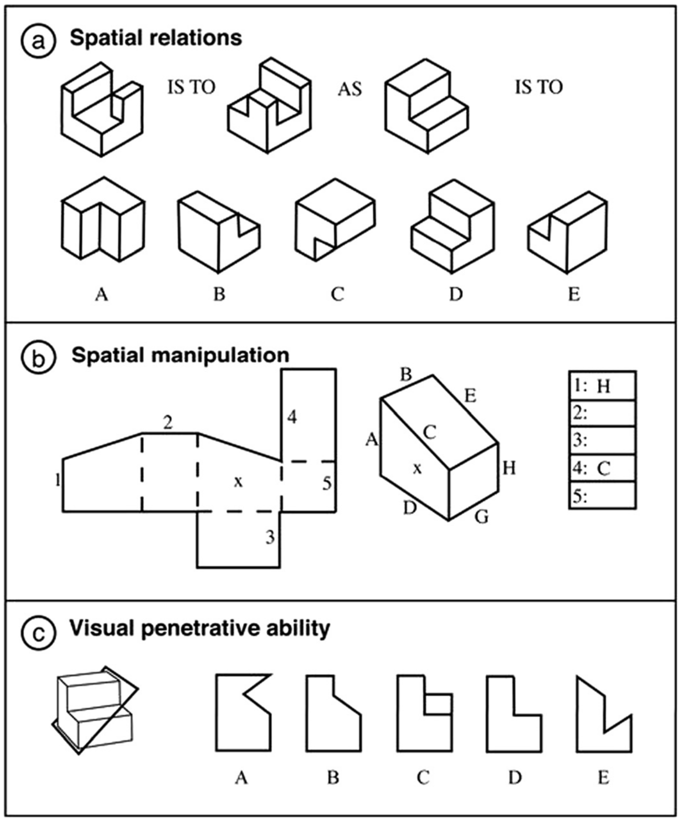

FIGURE 1: Three component spatial visualization skills essential to geosciences (from Titus and Horsman, 2009).

With respect to geologic time, King (2008) describes two aspects that geoscientists must conceptualize. These include (1) the vastness of absolute or "deep" time (McPhee, 1981), and (2) relative time, including the temporal correlation of stratigraphic units and sequencing of events. Both of these concepts are fraught with misconceptions among students and teachers alike (Ault, 1982; Schoon, 1992; 1995; Trend, 1998; 2001; Libarkin *et al.*, 2007).

Spatial visualization ability and the concept of relative geologic time are intimately linked. Dodick and Orion (2003) describe aspects of the three-dimensional relationships among strata, including superposition and original horizontality, as a means by which students determine their temporal organization. Their 2003 study demonstrated a strong correlation between students' spatial visualization skills and their ability to correlate geologic strata in time. They also discovered that these skills are in turn influenced by the student's ability to reconstruct geological and biological change through comparison of sediments and fossils with contemporary environments and biota. Further, their study indicated a significant difference in these spatial-temporal thinking abilities between students in grades 7–8 and 9–12. They therefore suggested that middle school earth science programs should focus on problems involving stratigraphic correlation, and actualistic thinking, together with associated content knowledge. They propose that improving students' understanding of spatial relationships, which would in turn improve their understanding of temporal organization, might be best approached by working on structures in the field, "the true test of all geological understanding." In order to assist students with spatial and temporal visualization, however, teachers must feel comfortable with their own proficiencies in essential geosciences skills. Only then will classroom practices be transformed and students' learning improved.

THE PALEO EXPLORATION PROJECT

In September of 2006 The University of Montana began an ambitious three-year outreach project funded by the National Science Foundation's Innovative Technology Experiences for Students and Teachers (ITEST) program. The "Paleo Exploration Project" (PEP), provided teachers and students from chronically underserved K–12 schools in eastern Montana an opportunity to work with university scientists in a structured program combining geospatial technologies with geological and paleontological exploration. The intent of the program was to strengthen participants' understanding of essential geoscience concepts, tools, and skills (Stanley and Almquist, 2008).

The PEP program had three components: (1) a series of three weekend workshops for teachers, (2) a week-long summer research institute providing hands-on field experiences for both teachers and selected middle school students, and (3) development and classroom implementation of teachers' own inquiry-based projects. Although PEP was primarily designed as a professional development outreach program, rather than as a research program, it did provide insights into effective ways to improve teachers' attitudes and abilities in using geospatial technologies to support inquiry-based learning.

Fifty teachers in two cohorts completed the program over the three-year period, including 24 teachers in year 1 and 26 in year 2. Results from the first iteration of the program were used to make improvements for the second cohort of participants (Almquist *et al.*, in press). In this paper we describe how, in the revised program, weekend workshops followed by specific activities implemented during the summer institutes were designed to enhance teachers' geosciences skills. We also discuss how this pedagogical approach could be adapted for a variety of geologic settings.

PARTICIPATING TEACHERS

The second cohort of teachers, reported on here, included seven males and 19 females. One of the teachers was Native American and the rest were Caucasian. Eight teachers taught in tribal schools and one taught at a Hutterite colony. Because participating teachers were from predominately small rural schools, all taught more than one subject and grade level. Nine of the PEP teachers taught grades 6–12; nine taught grades 3–5; three teachers taught grades 9–12; three taught K–8; and one taught grades 6–8. The group also included one guidance counselor and a school technology coordinator. Teachers' teaching experience also varied widely. Seven teachers had one to five years experience, four had been teaching four to six years, eleven had 11–20 years experience, and four had been teaching for more than 20 years.

Only six of the teachers had undertaken geoscience-related coursework at the college level and only three had any prior training in Geographic Information Systems (GIS). Seven reported having some familiarity with either Global Positioning System (GPS) or Google Earth.

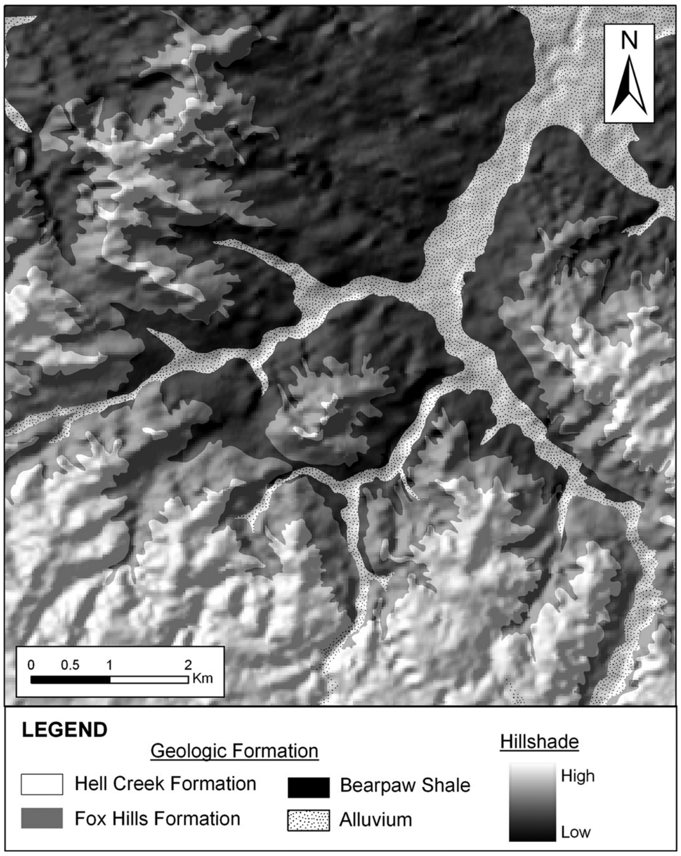

FIGURE 2: Example GIS map of a portion of the summer fieldwork area showing how Late Cretaceous geologic formations relate to topography.

WEEKEND WORKSHOPS

The weekend workshops were designed to prepare teachers for the summer field experience, including providing them with relevant content knowledge in geology and paleontology, allowing them to visualize the research area through GIS mapping exercises, and training them in specific field techniques.

Workshop Content

Teachers received instruction on the geologic history of eastern Montana and attendant geologic formations. They reviewed the relevant portions of the geologic time scale (Late Mesozoic through Cenozoic) and principles of stratigraphy, and learned about sedimentary and fossilization processes. At each workshop, time was allotted for hands-on examination of representative specimens of eastern Montana's major fossil assemblages. These samples primarily included diagnostic fragments typically encountered in the field in eastern Montana, rather than fully articulated, museum-quality specimens.

Training in geospatial technologies began with an introduction to Google Earth because it had proved to be an effective entryway for people with little spatial technology background (Almquist *et al.*, in press). The group then progressed to ArcMap (ESRI ArcGIS 9.2). After learning basic ArcMap skills such as adding layers, changing symbology, working with attribute tables, and conducting queries, teachers reviewed basic map functions, design elements, layouts, and production. Working from prepared data sets, they then created geologic maps of the area surrounding Fort Peck, Montana, where the summer fieldwork would occur (Fig. 2). Intrigued by the idea of finding specific types of fossils, the teachers integrated various data layers, including geologic formation, land ownership, and roads, to identify accessible sites to explore. They also used aerial photograph overlays, digital elevation model (DEM) data, and hillshade shape files (depictions of terrain or relief derived from digital elevation data) to further examine topography and locate geologic exposures within candidate sites.

Teachers also were instructed in geological field techniques, including paleontological sampling, measuring sections, and field preparation. In outdoor activities, they learned how to use GPS receivers for finding and recording locations of interest and practiced note taking protocols. During these sessions, they conducted mock fossil surveys to practice GPS use and subsequent mapping of fossil distribution in ArcMap. They also measured a series of mock "stratigraphic columns" (large-format paper illustrations) in field notebooks, interpreting the sediments depicted at each station, and using all profiles to reconstruct the geologic history of the "research area." In addition, they learned how to operate a Leica TC 307 total station to survey landforms. These are optical instruments that combine an electronic transit, electronic (laser) distance meter, and data collection software for precision 3D surveying (Philpotts *et al.*, 1997).

Teacher Survey Responses

At the culmination of each workshop, teachers reported changes in their "comfort level" with various content domains (GIS, Montana geology, and field techniques) and what they liked or did not like about the workshops. After the third workshop they also reported on how prepared they felt they were for the upcoming summer field sessions.

All teachers reported benefiting from these workshops, including increased comfort levels with the geological content, as well as increased skills and confidence in using spatial technologies. Three of the 26 teachers reported feeling overwhelmed by the science content conveyed during the first workshop, but gained confidence over the following sessions. Over a third of the teachers (39%) mentioned the hands-on mock field exercises as the best part of the third workshop, with 50% saying they would have liked to have spent more time on this segment. Several commented that they wished they had been able to visit real sites. All teachers reported an increased comfort level with field techniques, and 84% reported feeling "enthusiastic" about attending the summer research institutes.

SUMMER RESEARCH INSTITUTES

The summer research institutes took place in one of the most fossil-rich areas of the American West. Local outcrops yield a wide variety of marine invertebrates including ammonoids, both marine and terrestrial reptiles, and plants. In addition, the Fort Peck region (Roosevelt, Philips, McCone, Richland, Garfield, and Valley counties, Montana) contains extensive exposures of Upper Cretaceous rocks that exemplify classic intertonguing stratigraphic relationships between nonmarine sediments deposited on the western coastal plain of the Cretaceous Interior Seaway and marine sediments deposited in the seaway. Paleo-environments available for study include terrestrial floodplain, lake, river, transitional marine (beach and marsh) environments, and fully marine settings (offshore shale) (Weimer, 1960). The Fort Peck region has been tectonically stable, resulting in relatively undisturbed layer-cake stratigraphy with rock units occurring at more or less consistent elevations.

This setting is ideal for demonstrating principles of stratigraphy, paleontological succession, and aspects of relative geologic time such as stratigraphic sequences and temporal correlations. The layers represent environments that are distinctive, which aids in their interpretation using actualistic thinking. Finally, the entire landscape has been intensely eroded into a badlands-style topography, resulting in numerous exposures useful for developing spatial thinking skills such as visual penetrative ability.

During the summer research institutes, groups of participating teachers and selected middle school students engaged in a variety of field-based activities designed to help them develop these understandings and thinking skills in the context of authentic geologic fieldwork. The primary activities included (1) documenting the stratigraphy of an ancient (Eocene) river channel and (2) conducting a tour of four Late Cretaceous geologic formations. These field sites were all on U.S. Bureau of Land Management (BLM) land near the state highway. Necessary permits were secured in advance to allow participant access. Following BLM guidelines, fossils were observed but not collected, and soil disturbance was kept to a minimum. Participants also experienced a unique opportunity to help paleontologists from the University of Montana Paleontology Center excavate a *Triceratops* head shield from a private ranch.

Participants were divided into groups of three to four teachers and six to eight students. These groups worked together throughout the week. The intermingling of students and teachers was an intentional design to help teachers gain confidence in their own newly aquired content knowledge by teaching students in the field. University instructors acted as field guides, facilitators, and discussion leaders, supporting the teachers and providing content and technical expertise as needed.

Participants were provided with the materials necessary to examine the rock exposures and record their field observations, including hand lenses, digital cameras, scale bars, grain-size charts, note books, pencils, and GPS receivers. At each site visited, they were expected to practice using content understanding and scientific thinking, including making appropriate observations, evaluating multiple lines of evidence, and constructing valid scientific arguments, to infer the nature of the environments and time periods represented. During discussions, instructors helped lead participants in metacognitive reflection, encouraging them to evaluate their evidence, consider alternative explanations, and justify their conclusions. Participants' understanding of key concepts was demonstrated by their ability to make and interpret observations in the field, their answers to the instructors' questions, and by the nature of their questions and comments to the instructors.

Mapping an Exposure of the Fort Union Formation

In this activity, instructors assisted participants in mapping a large exposure of the Tullock Member of the Fort Union Formation located southeast of Fort Peck. The Tullock dates to the Early Paleogene, with an unconformity separating it from the underlying latest Cretaceous Hell Creek Formation. At its type locality, the Tullock Member represents a low-gradient fluvial system and is characterized by interbedded sandstone, siltstone, shale, and coal (Brown, 1986).

The specific objectives of the mapping exercise were to provide participants with experience formulating hypotheses regarding the depositional setting of the Tulluck Member and testing those hypotheses through direct field based observations of sedimentology and stratigraphic architectures. Participants documented the Tullock Member at the study site through measured stratigraphic sections, photography, physical ″walking out″ of key beds, and total station surveying technology, which allowed the field observations to be captured on a 3D digital grid at a resolution of 10 centimeters or less.

While in the field, the entire group was subdivided in to two teams that switched duties half-way through the day so as to provide participants with experience in all facets of the field work. Prior to data collection, the entire study group formulated a lead hypothesis for interpretation of the Tullock depositional environment and developed the experimental design to test the hypothesis. In the field, one team used total stations to survey the lateral positions of specific stratigraphic surfaces across the study area, while the other team went about measuring one or more stratigraphic sections that were tied to the total station survey.

During the total station work, instructors and students rotated duties between operating the total station instrument, placing the surveying rod on the targeted stratigraphic surface, and serving as coordinator and communicator. (Due to the relatively long shot distances involved, communication between the surveyor and person placing the rod required a two-way radio.)

During the stratigraphic section work, student-teacher teams made observations with respect to strata thickness, lithology, sedimentary structures, and fossil content and recorded these observations on a graphical measured section. With help from the teachers and instructors, students learned how to measure stratigraphic sections, describe individual stratigraphic layers, and collect sediment samples for further analysis in the laboratory. Participants used the sedimentary evidence they had collected, including layer color, estimates of grain size (mud, fine, medium, and coarse sandstone), sedimentary structures, fossil content, and relative stratigraphic position to interpret temporal changes in the environment at each measured section (Fig. 3).

The Tullock Member lends itself particularly well to this type of sedimentary architectural analysis because it contains well-displayed channel forms that can be easily captured in the overall field data set. Through this work, student-teams were able to document convincingly the presence of an erosional incision on the base of a major channel that was part of a low-gradient river system (Fig. 4).

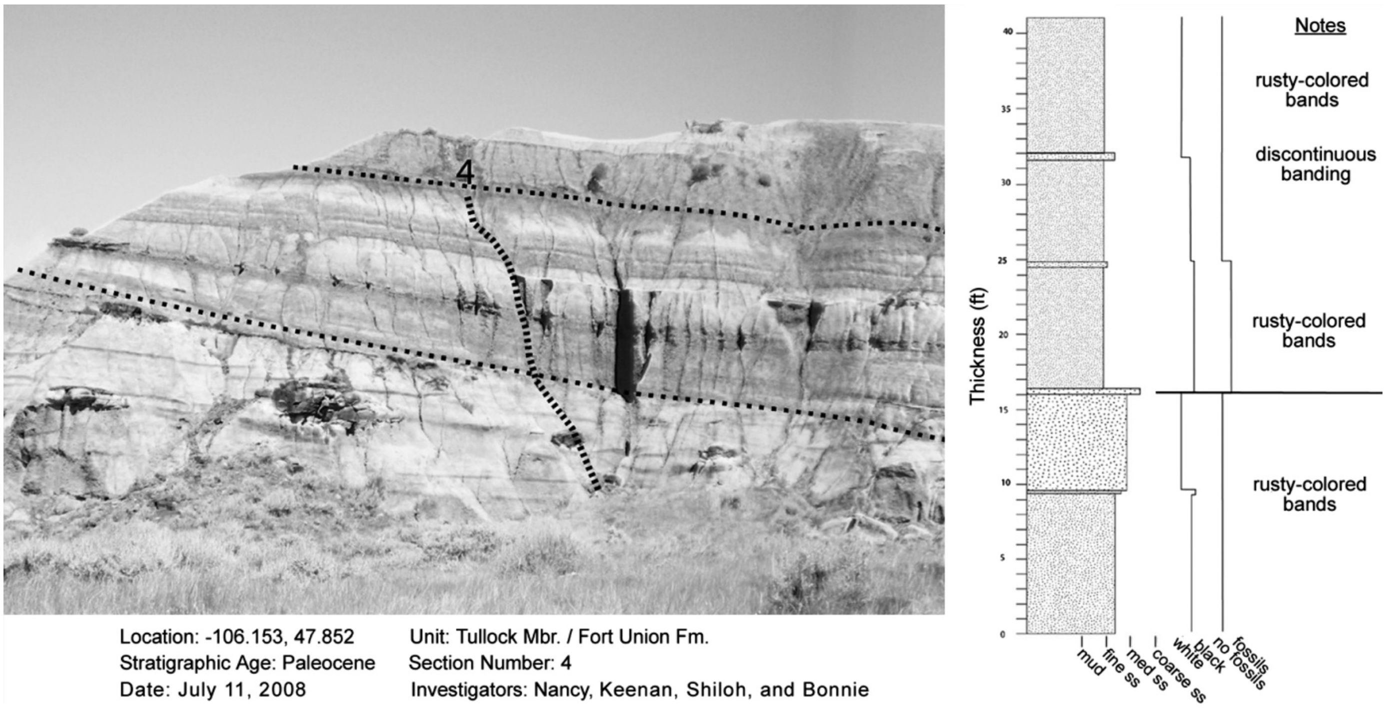

FIGURE 3: Example of students' stratigraphic work in the Tullock Member of the Fort Union Formation. The location of the stratigraphic section shown on the right is depicted by the steep vertical line on the photo to the left. The two other gently tilted dashed lines in the photo are two stratigraphic surfaces surveyed with the total station.

The Late Cretaceous Tour

The objectives of the Late Cretaceous Tour were to help teachers solidify understandings gained during the weekend workshops and to introduce students to key geosciences concepts and skills, including (1) the principal of superposition—that in an undisturbed sequence of layered sedimentary rock, younger rocks overlay older rocks, (2) that different environments leave behind diagnostic sedimentary rocks and fossils, (3) how fossils and sedimentary rocks can be used to discern ancient environments, and (4) the rates and magnitudes of environmental and biological changes that have occurred throughout Earth's history.

The tour included stops at four geologic exposures representing distinct geologic units (see Field Trip Guide). This sequence progressed from older to younger strata beginning in the Western Interior Seaway and ending with the mass extinction event at the end of the Cretaceous Period. Upon reaching each site, participants were asked to walk around on their own and make observations about the rocks (including sediment color and texture), fossils, elevation, and topography of the area. They were to document these observations in field notebooks with accompanying photographs and GPS locations. The group was then called back together and asked to report their observations. They were told to compare these observations with what they observed at the previous stop, noting any differences. Instructors asked a series of questions to help participants further explore their observations and asked them to use these lines of evidence together with their knowledge of the regional geologic history and their own prior experience to infer the depositional environment. In contrast to many geologic field trips, instructors were careful not to reveal information about the site until after participants had reached their own conclusions. Participants' understanding of central geologic concepts and ability to think spatially and actualistically were demonstrated by their observations, reasoning, conclusions, questions, and comments.

RESPONSES TO THE PROGRAM

Teacher interviews, which were conducted during the final days of the institutes, provided the first evidence that the program had increased teacher confidence in and understanding of core geosciences skills. During the interviews, teachers talked most about hands-on experiences, technology training and applications, their interactions with the university scientists, and using their acquired knowledge and skills with students. Teachers were both excited and surprised by the amount of hands-on activity they took part in. Regarding the field experiences, a typical comment was "I had a feeling that we would be doing hands-on, and we would be going out, but I didn't know that it would be so much. I think it's great that we can go out and actually experience each one of the formations and see what's there." Teachers reported feeling ready to take their acquired skills and knowledge back to their own classrooms. "I can't wait to get the students as enthused as I am," one teacher commented.

Both teachers and instructors confirmed that the weekend workshops had helped prepare teachers for the summer field experience and that most teachers were able to relate what they had learned during the workshops about the geologic units, fossils, and depositional environments to what they observed in the field. Teachers helped students make good observations that enabled them to ask relevant questions and develop plausible explanations such as "this has characteristics of a beach environment,

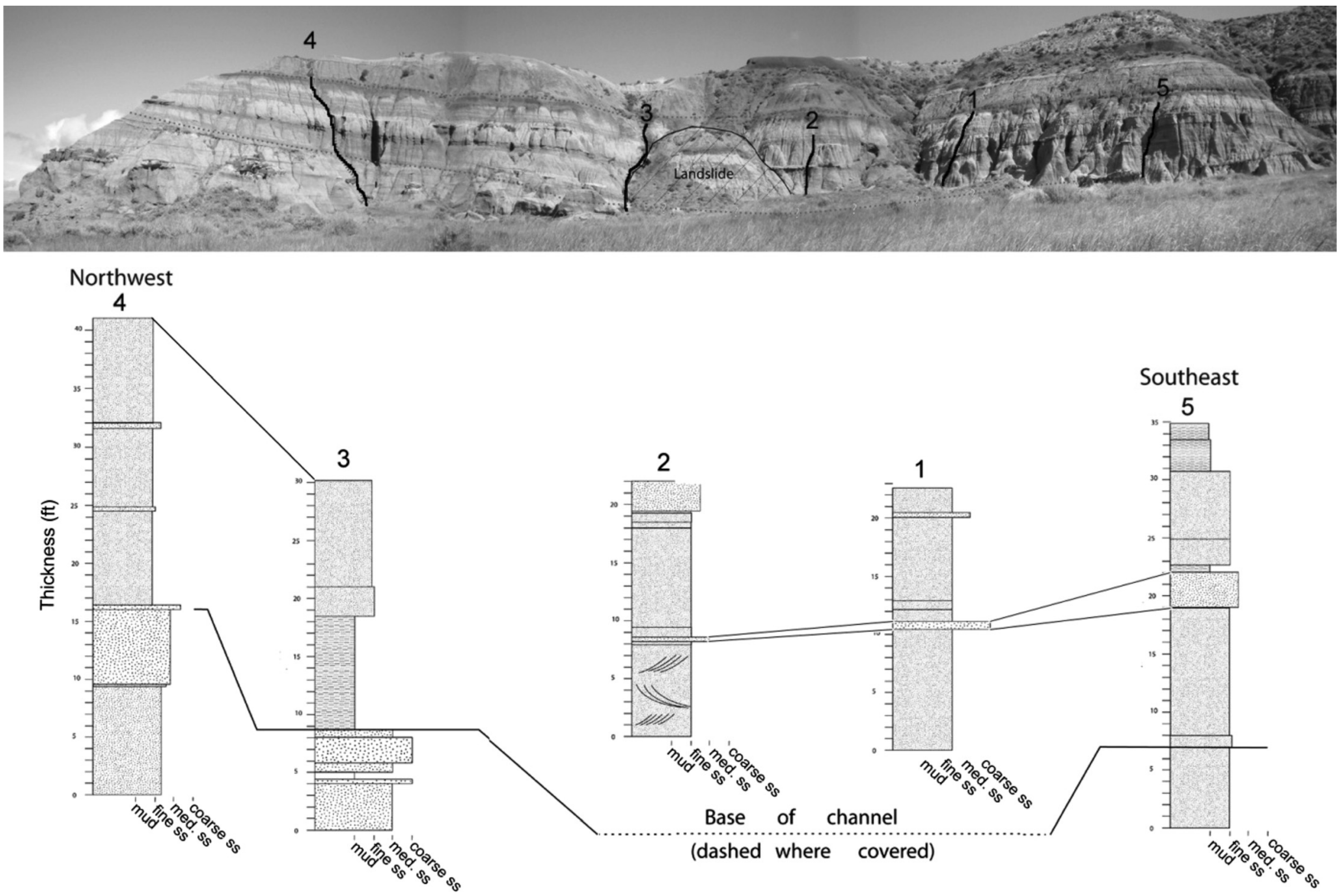

FIGURE 4: Discerning an ancient river channel through correlation of layers at the Tullock exposure. ("ss" = sandstone).

such as well-sorted and rounded sediment grains and cross-bedding" or, "we are at a higher elevation than we were at the previous stop so are probably in a younger layer of strata."

Instructors felt they had played an important role in helping participants think scientifically. For example, instructors posed questions requiring participants to develop explanations based on their observations. "Given this combination of sedimentary characteristics what would the depositional environment have been 75 million years ago at this site? If little elevation change has occurred since the time of deposition, does the elevation of this site tell us it is younger or older than the last formation we visited?" Instructors felt that most participants were able to work together to determine the depositional environments and relative time periods represented.

Student interviews conducted during the institutes revealed that they were also excited about what they had learned. "I didn't suspect that we'd learn about all the rocks and levels and all that," one student said. "We learned how the colors of the rock change; there's purple and yellow and green and brown and gray, and all these other colors—how they changed…" another responded. From the instructors' point of view, the majority of students were able to grasp the essential concepts and actively participate in scientific discussions. However, some students appeared distracted and preoccupied by the fossils, rocks, or other students, and were unable to make the necessary observations.

As part of the PEP program, all of the teachers were required to create and (if possible) implement their own spatial technology embedded, inquiry based learning activities in their classrooms. All of the teachers completed these assignments. Many of the activities were related to the geosciences, depending on the teachers' 2008–2009 teaching assignments. Others focused on history, mathematics, geography, or biological science.

At the end of the 2008–2009 school year (one academic year after the summer institutes), 24 teachers from the second cohort responded to an on-line survey consisting of 18 multiple choice items and one constructed response item. The survey addressed content, skills, and pedagogical knowledge learned and implemented in the classroom as a result of PEP. External evaluators also conducted individual, face-to-face interviews with 17 of the teachers. These interviews focused on the teachers' own growth, changes in their classroom practices, impacts on students, and planned future uses of skills and content gained through the program.

In the interviews, teachers were asked, "What has been your greatest area of growth since participating in PEP?" The majority of participants (59%) indicated that geospatial technology skills were their most important area of growth, while 29% felt their greatest growth was in

TABLE I: Changes in Your Understanding and Skills in Implementing the Following Elements of Inquiry Learning.

	Significantly		Somewhat		A little		Not at all		Total	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Learners engaged by scientifically oriented questions	5	11	11	10	7	3	1	0	24	24
	20.8%	45.8%	45.8%	41.7%	29.2%	12.5%	4.2%	0%	100.0%	
Learners give priority to evidence to develop and evaluate explanations	4	10	12	12	3	2	4	0	23	24
	17.4%	41.7%	52.2%	50.0%	13.0%	8.3%	17.4%	0.0%	100.0%	
Learners formulate explanations from evidence	4	10	14	10	6	3	0	0	24	23
	16.7%	43.5%	58.3%	43.5%	25.0%	13.0%	0.0%	0.0%	100.0%	
Learners evaluate their explanations	4	12	14	9	5	3	1	0	24	24
	16.7%	50.0%	58.3%	37.5%	20.8%	12.5%	4.2%	0.0%	100.0%	
Learners communicate and justify explanations	4	13	13	8	5	3	1	0	23	24
	17.4%	54.2%	56.5%	33.3%	21.7%	12.5%	4.3%	0.0%	100.0%	

content knowledge. When asked what the most important aspect of PEP was, the most common response, which came from 36% of participants, was updating knowledge to improve their teaching. When specifically asked how PEP had affected their teaching, 82% mentioned the use of geospatial technologies, with most indicating increased use of GPS, GIS, or ARCView.

These interview responses were supported by results of the online survey, which specifically asked how frequently teachers used the skills, tools, knowledge, and concepts they acquired from PEP in their teaching. Fifty percent stated they use them throughout their teaching and 37.5% that they use them frequently. The remaining 12.5% said they use them infrequently, and no teachers reported not using them at all.

The use of inquiry approaches in teaching and student learning was also an area of emphasis in PEP. The programmatic approach was to provide teachers practice in the elements of inquiry so that they could find opportunities to incorporate these elements throughout their teaching. Teachers had been asked to report on their use of various elements of inquiry in a preprogram survey and were asked the same questions on the survey taken one year after PEP.

Comparison of the pre- and postprogram survey results suggest dramatic change in teachers' use of inquiry as a result of PEP (Table I), with each teacher progressing along the continuum of including more elements of inquiry into their teaching. On all of the elements, fewer than 21% of the teachers believed they were "significantly" using these elements before PEP, while after the program over 41% reported "significant" use. After PEP, all teachers reported using these elements; and the percentage of teachers using it "a little" also decreased.

In the interviews, teachers also reported on how their participation in PEP had affected their students. Several teachers noted that learning about the growing importance of geospatial technologies in many careers was an "eye-opener" for students. About a third (35%) of the teachers talked about geospatial technology skills or geological content knowledge. But most of the teachers (82.6%) also mentioned more general outcomes relating to increased student engagement, motivation, or exposure to science and technology.

When asked, "How will you use what you learned in PEP in the future?" half of the teachers said that they would use what they learned to incorporate "more mapping" into subject areas. Specific responses included the following:

- Teach more GIS and use more data layers
- Add analysis and interpretation of the GIS data
- Connect GPS/GIS with careers
- Plan a GPS Easter egg hunt, featuring peer learning (in lower elementary grades)
- Combine crop soil testing with Google Earth mapping (at a Hutterite colony)
- Plan additional technology based projects
- Expand use of GIS from the high school to the middle school level
- Replace an AutoCAD curriculum with the ArcGIS curriculum
- Start an elective after-school class to present PEP materials in order to spark more interest in science (at a tribal school).

Following the 2009–2010 school year (two academic years after completing PEP), 16 teachers responded to an on-line survey focusing on changes in their instructional practices as a result of PEP. In this survey, 81% of respondents reported that they use GPS receivers with their students; 75% reported ongoing use of Google Earth, and 44% reported using GIS in their classrooms. Seventy-five percent reported confidence in "designing lessons that effectively combine content, technologies, and teaching strategies," and 67% reported that their participation in PEP continued to influence what and how they teach. Typical responses included the following:

- "We usually do a project using GIS and I wouldn't have done that before."
- "We have been using GIS and Google Earth in my classes this year. The students have increased their knowledge of geospatial technology and paleontology a lot."

- "I use a lot of the experiences I learned in PEP in my teaching. I can't do GPS or Google Earth projects every day, but I do use them extensively when they are called for. I used several of the ideas/technologies that I had experience with in PEP to engage my students."
- "PEP has greatly influenced how I teach science and geography. We now use Google Earth, Power Point, and I can really extend on fossils and land formations."
- "I have now incorporated several projects into my classes that follow a lot of the format that we did during the PEP course…including having the students design a project, use appropriate technologies to carry it out and collect data, and present their projects in Power Point format. "
- "I believe that by being engaged in the new material that PEP introduced to me, I am more apt to try out and introduce new technology to my students. Because of the careers associated with GIS and mapping, I am able to encourage my students to give that serious thought for their own careers and can offer them real examples and experiences as to how they can apply what they have learned into real, high paying jobs."

A teacher of grades 3–5 offered the following description of her own experience. "PEP allowed me to step out of my comfort zone which prompted my building self confidence in my abilities with technology. My participation also promoted my expansion of new technology and how it can be utilized effectively in classroom instruction. I find myself exploring new avenues to use the knowledge I gained through PEP to bring instruction alive in my classroom, no matter what curricular area I am teaching. I have even taken another course that provided a little more confidence in venturing towards using GPS, Google Earth, etc. in my classroom this next school year. As with all things new, I get very excited, yet a good percent of change happens in small steps so that I make sure it continues. In turn I will add more every year to keep the experience moving forward."

DISCUSSION

The primary goal of the Paleo Exploration Project was to construct a program that would help teachers develop essential understandings, thinking abilities, and technical skills important to the geosciences, including: (1) specific geology-related spatial visualization skills, (2) an understanding of absolute geologic time, including the concepts of sequencing and temporal correlation, (3) actualistic thinking, or the ability to interpret ancient environments through comparison with modern ones, (4) geological field strategies and techniques, and (5) scientific reasoning. This goal was admittedly lofty, given that, like many elementary and even secondary school science teachers, most of the PEP teachers had little geoscience background.

Teachers often express concern about being able to effectively teach new material unless they themselves are comfortable with the requisite skills and understandings. Thus, teacher professional development is essential to incorporating visual-spatial teaching and learning into science education through in-service and teacher preparation programs (Mathewson, 1999). Further, teachers teach best from their own first-hand experiences. Thus, professional development programs should incorporate a variety of learning activities, including authentic field-based experiences. The PEP professional development program also demonstrated that intense preparation of teachers prior to the field component is important for success. This approach was highly praised by participants.

PEP was unique in many ways. It served a diverse group of K–12 teachers from Montana's frontier communities; it explored a unique and fascinating geologic setting; and it introduced a specific set of geologic principles and field techniques related to the study of that geology. However, the key aspects of the program could be replicated in almost any surroundings with almost any group of teachers. Here we describe the most important programmatic elements and how they could be replicated elsewhere.

Familiar Landscapes

PEP focused on local landscapes that were meaningful and accessible to teachers and their students both during and after the program. Using familiar landscapes allows learners to build on their own prior knowledge and to place new information within an existing framework. All landscapes tell a story. It makes little difference if the tale is about glaciations, volcanism, uplift, or weathering, to name just a few. A program's content should reflect what is best illustrated in the landscape at hand.

An Engaging Quest

Within the context of the local landscape, programs should also center on an engaging quest. In PEP, teachers' interest in locating and documenting prospective sites for fossil discovery motivated them to tackle ArcView so that they could examine and overlay a suite of geologic and geographic variables. Similar geospatial challenges could be utilized in other contexts, such as finding rare mineral deposits, or selecting sites for geothermal energy production.

Relevant GIS Data and Skills

Many PEP teachers found GIS challenging to learn and consequently, the PEP GIS instruction evolved over the course of the program. We found that using lesson plans and data layers customized for the planned fieldwork proved much more effective than using a generic GIS tutorial and data sets. The customized lessons and data took some effort by staff to develop, but definitely made the GIS more interesting and relevant for teachers and helped better prepare them for the upcoming fieldwork.

Integrating 2D to 3D Maps Using GIS

Integrating two-dimensional geologic maps with three-dimensional geologic structures is difficult for many people (Ishikawa and Kastens, 2005). In PEP, teachers' use of GIS maps that included hill shade or DEM layers and aerial photography overlays appear to have provided a useful interface between traditional topographic maps and real-world features. We would therefore recommend using such GIS layers to enhance topographic perspective prior to conducting fieldwork.

Practicing Tools and Field Techniques

Fieldwork introduces many variables and real world complications to the learning process, but can be managed if learners are given adequate preparation in applicable geologic background and field techniques. The tools and techniques presented should be specific to the anticipated fieldwork and learners should be given significant hands-on practice to become familiar with them. Ensuring this will save both time and frustration in the field. PEP teachers greatly appreciated the outdoor, hands-on activities with total stations, GPS, and note taking protocols prior to conducting fieldwork.

Exposures for Visualizing Structures

In eastern Montana, badlands provide nearly unlimited geologic exposures to aid in spatial visualization of the subsurface stratigraphy. However, other types of geologic exposures, including cliffs, river cuts, gravel pits, road cuts, and even building excavations, could be used to provide snapshots of the larger buried geology. The key is to provide a suite of exposures with enough continuity to allow learners to visualize geologic connections across the landscape.

An Inquiry Approach

Field activities emphasizing observation and deductive reasoning were emphasized in PEP and can be employed nearly anywhere. Whether examining sedimentary structures in sandstone, exposures of glacial till in gravel pits, or folded or faulted sequences in road cuts, for example, learners benefit from the opportunity to play the role of investigator, developing their powers of observation and deductive reasoning abilities, and engaging in scientific discussion and argument. This process can be a very instructive and enjoyable aspect of the field experience. However, to be successful, instructors must be skilled mediators and be able to resist the temptation to "show and tell."

Metacognitive Reflection

Another critical aspect of the PEP field program was the metacognitive reflection encouraged by instructors (Bransford *et al.*, 2000). During discussions at each site visited, participants were led to reflect on the nature of the empirical evidence they had observed and on the completeness and validity of the arguments they used to support their claims. This approach appeared to help participants construct valid scientific arguments, supporting their claims with well vetted evidence and concrete reasoning. Other authors have also found that when working with geologic concepts, preservice elementary teachers responded well to inquiry-based activities coupled with discussion (Petcovic and Ruhf, 2008).

Working with Students

PEP teachers reported that having an opportunity to work with students in the field was important in helping them solidify their own content understandings and gain confidence for future classroom teaching. Teachers appreciated being able to practice various teaching approaches to determine how students would respond. Within their small groups and in casual conversations during the evening hours, they were able to confer with other teachers in developing best practices. Many teachers commented that working with students within the professional development experience was a unique and laudable aspect of the program. It is an approach we highly recommend.

LIMITATIONS TO THE APPROACH

We believe that the fundamental aspects of the PEP program described above could be replicated in a broad array of geologic settings to serve a variety of teachers. However, field-based approaches are not without pitfalls. For example, managing large groups in the field is very costly. It requires a lot of experienced personnel to keep everyone safe and comfortable, so that significant learning can take place.

Involving students also adds complexity. Keeping children engaged in outdoor settings is challenging, and middle school students vary greatly in maturity level and attention span. Studies show that the "novelty space" of a field situation, including cognitive, psychological, geographic, and/or social aspects that are new to students can interfere with student learning (Orion and Hofstein, 1994; Cotton and Cotton, 2009). During the institutes, some students appeared distracted by the fossils and rocks they discovered and were unable to think about the bigger picture. This problem might be alleviated by adding another day or two of orientation during which students are introduced to the field settings and field techniques, including how to locate and describe fossils, prior to involving them in the research activities. In essence, we recommend extending the intense and successful preparation of teachers undertaken in PEP to the preparation of students.

In addition to preparation, all participants must be given time within and after their field excursions to assimilate what they have experienced. A final group activity could be designed to accomplish this. At the same time, both participant preparation and retrospection would require additional time and it is difficult for most teachers to spend more than one week in such a program, even if they are provided stipends, and being away from home for more than a week can be difficult for many middle school students.

Ultimately, the measure of any teacher professional development program is its impact on actual classroom teaching practices. This transfer of skills and understandings to students presents additional challenges. Some teachers report that inadequate in-school computer technology inhibits their use of some geospatial technologies in the classroom. Others have difficulty finding time to introduce new material within an already overloaded curriculum, or lack funding for field trips or other hands-on activities. Some teachers reported needing additional opportunities to refresh and build upon the skills and understandings that they acquired through their professional development experience.

RECOMMENDATIONS FOR FUTURE WORK

Future research efforts utilizing validated assessment instruments to document progress in the development of geoscience skills by teachers over the course of such a program, as well as by their students through subsequent classroom experiences, would help clarify the students' learning progression from naïve to more sophisticated geoscience skills and understandings. Future work could also be aimed at determining how various aspects of novelty space influence field-based learning by students of different ages and how negative influences on learning might be mitigated.

Longitudinal studies aimed at determining longer-term impacts on teachers' classroom practices would also be beneficial. Such studies should incorporate classroom observations using standard protocols to validate or calibrate teachers' self-reported data, as well as both affective and achievement oriented student outcomes. In summary, studies aimed at determining best practices for teachers and students within specific grade bands could result in a scaffolded continuum of exemplary technology-embedded field-based approaches for geosciences education.

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