MEASURING THE EFFECTS OF A RESEARCH–BASED FIELD EXPERIENCE ON UNDERGRADUATES AND K–12 TEACHERS

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ABSTRACT

During the summer of 1999, a new type of field course was taught in five of eastern Utah’s National Parks and Monuments. The course was unique because it targeted a combination of university undergraduates and K-12 teachers, emphasized development of participants’ problem-solving skills, and assessed the effectiveness of several non-traditional teaching methods. The course’s primary goal was to teach participants to develop and test their own ideas. The course also was designed to help participants learn to use tools and methods employed by research scientists. A mix of undergraduates and teachers was targeted so that the course could be used to introduce undergraduates to the concept of teaching as a career.

A blend of pedagogical components was employed and tested during the course. Pre- and post-course attitudinal surveys, instruments designed to measure lower- and higher-order cognitive skills, diagnostic learning logs, and post-course interviews were used to assess the course’s success at achieving six specific goals.

The course produced an immediate impact on the attitudes, career choices, and lower- and higher-order cognitive skills of student participants. Although the initial results are intriguing, the assessments are not statistically significant for a variety of reasons including small sample size. Subsequent offerings of the course will be assessed in similar ways so that results can be interpreted with more confidence in the future.

Keywords: Education – testing and evaluation; education - geoscience; education – earth science; education – undergraduate; education – teacher education; geology – teaching and curriculum; education – pre-college; education – science; field trips; field study; summer field courses.

INTRODUCTION

A new, two-week long, field-based, earth science learning program targeting lower-division undergraduates and professional teachers was first implemented at Michigan Technological University during 1999. The course differed from traditional senior-level field camps in four main ways. First, the course targeted a mix of lower-division undergraduates and professional teachers. Second, its participants continually applied geoscience concepts and techniques to develop hypotheses in response to open-ended research-type problems. Third, the course employed and evaluated a blend of teaching methods consistent with the educational constructivist school of thought. Finally, the course’s effectiveness at reaching a set of outcome-based goals was assessed. Although the course continues to be taught, this paper focuses only on the initial offering.

Development of the course was motivated by recent calls for revision of geoscience curriculum at all educational levels (National Research Council, 1996). University geoscience departments have traditionally exposed their undergraduates to the methods used to study the Earth and the results of previous research through a sequence of courses. Each course strives to present students with information about a specific geoscience sub-discipline. Courses such as structural geology, tectonics, and sedimentology, among many others, teach students valuable skills that will be useful throughout their careers. Although the courses are designed to build knowledge progressively, the concepts common to all (e.g., fluid flow, stress and strain) typically are not emphasized as such. Some students come to feel that their education is composed of a series of unrelated elements, leading to feelings of frustration and lack of motivation. Faculty members aware of their students’ dissatisfaction are often unable or unwilling to make the changes necessary to stimulate students’ interest and active participation within the confines of a term-dependent and topic-dependent curriculum.

Statements in the preceding paragraph are based in part on analysis of information collected at our university as part of a formal assessment program initiated during 1997 in response to guidelines issued by the North Central Association. Exit interviews with graduating seniors suggested student interest and motivation were highest when students perceived the teacher was interested in the subject matter, and when the subject matter directly pertained to the students’ own interests. Although students in a technically rigorous program will graduate possessing the knowledge and skills required to pursue careers successfully, at risk is the enthusiasm for scientific inquiry, interest in life-long learning, and ability to adapt to new situations that characterize excellent researchers and teachers (Rutherford and Ahlgren, 1990). Our course was designed to address and remedy students’ lack of understanding about the interrelations between courses. Prob-
lems posed to participants throughout the course emphasized the importance of Earth processes in producing geologic features, and the importance of a holistic, Earth-system approach in geoscience (Ireton and others, 1996).

Development of the course also was motivated by the need for qualified elementary and secondary science educators nationwide. It is widely recognized that the need for talented Earth science teachers continues to grow, while the number of students seeking to become secondary Earth science teachers falls well short of demand (American Association for Employment in Education, 1997). In some geographic areas, up to 40% of teachers teach outside their academic preparation (National Center for Education Statistics, 1997). There is some indication that students do not enter Earth science education programs because they do not identify with Earth science teachers (Pigge and Marso, 1997). We recruited a mix of students and teachers because we suspected that undergraders who established connections with professional educators during an extended field experience would be more likely to pursue careers in teaching.

Students already interested in teaching also had the opportunity to establish contacts with practicing teachers during our course. It has been previously demonstrated that the more pre-service teachers are exposed to the teaching profession prior to student teaching, the more successful they are as student teachers (Pigge and Marso, 1997). Across the United States, state legislators, school boards, school districts, and teacher education programs recognize that the training of tomorrow’s teachers is enhanced when a prospective teacher receives the guidance, direction, and support of a seasoned teaching professional (Nath and Henry, 1997). Unfortunately, traditional teacher education programs tend to rely solely on student teaching as the mentoring experience.

Professional teacher participants were expected to benefit from the experience of applying new technical and theoretical concepts during the course. The course also exposed teachers to the use of non-traditional teaching methods. Although most teachers are aware that recent studies demonstrate a need for curriculum reform, many teachers appreciate seeing new methods modeled before they try to apply them in their own classrooms. If teachers observed and benefited from new methods while functioning as students, we hypothesized they would be more likely to apply and test new methods in their own classrooms. By incorporating teachers into the field-based course, we also had the opportunity to positively influence the educational environment for a large number of K-12 students.

Assessment was a vital component of the course’s design. The 1996 NSF-sponsored workshop on “Geoscience Education: A Recommended Strategy” (Correll and Bishop, 1997) detailed two crucial national needs: a path for curriculum reform in the geosciences, and a need for determining optimum learning strategies. Although there is a growing awareness of the need to reform the geoscience educational system, there are relatively few cases in which “reformed” education and its measured effectiveness have been presented to the geoscience community (e.g., Orion et al., 1997). Furthermore, although methodologies for assessing geoscience curricula are widely available (e.g., National Research Council, 1996), there is a need for documentation of how well procedures work in actual course settings.

**STRUCTURE OF THE COURSE**

The course was designed to teach participants to do scientific research. The field locations were chosen to allow focused emphasis on a variety of questions whose answers required an Earth-system approach. During the course, participants were exposed to a succession of rocks at a series of geographic locations (Table 1) that reflect the interaction of processes operating from Late Paleozoic to Cenozoic. With the help of visual aids (geologic maps, cross sections, air photos, etc.) and course instructors (faculty and teaching assistants), participants documented and interpreted rock characteristics that reflect the processes that formed them. Because of the long period of time represented by the rocks exposed at the field sites, the course was able to examine the effects of climate change, tectonic activity, and sea-level rise and fall.

Although our course was conducted primarily within the eastern Utah portion of the Colorado Plateau, this type of course could be taught anywhere. We developed exercises within and around five of eastern Utah’s National Parks and Monuments because these areas contain outstanding, well known, and in some cases unique, geologic exposures. The course was taught in areas of unquestionably superb geologic exposures because we wished to test the effectiveness of the course’s design. By ensuring the geology was exceptional, we were able to eliminate poor exposures as a potential cause of poor participant performance.

**A Typical Field Day** - At the beginning of each day of the course participants were given a “unifying question” (Table 1) to consider before they left camp. When necessary a brief (about 15-minute) overview lecture was also provided to give participants background information they would not be able to collect on their own. The entire group then traveled to the field site where participants were broken into small groups of four to five. The composition of each group was specified by the instructors and changed each day. When new skills or concepts were needed by participants to formulate plausible answers to the unifying question, participants worked through intensive instruction modules in a small group setting (four or five participants and one instructor). Typically the intensive instruction modules were held at the beginning of the field day. Participants spent all of the first field day working through intensive instruction modules, but the amount of formal instruction was progressively reduced on subsequent days. The intensive instruction modules covered topics like how to read a topographic map, how to use a compass, what techniques are used to identify unknown minerals, and how to take a strike and dip. After completing the intensive instruction modules, participants contin-
<table>
<thead>
<tr>
<th>DAY</th>
<th>LOCATION</th>
<th>UNIFYING QUESTION</th>
<th>HANDS-ON ACTIVITIES</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Paradox Basin, southeastern Utah. Pennsylvanian rocks.</td>
<td>How did the Pennsylvanian Hermosa group form?</td>
<td>Tectonic origin of basins. Correlation between well-logging tool responses and lithology and fluids. Make accurate sketches of large-scale structure to reconstruct geologic events.</td>
</tr>
<tr>
<td>4</td>
<td>Natural Bridges National Monument. Permian rocks. Quaternary geomorphology.</td>
<td>How are climate, sea level, and tectonic change reflected in these rocks?</td>
<td>Use a published geologic guide to identify features in the field. Make and sketch observations. Distinguish between ancient (Permian) and more recent (Cenozoic) geologic events.</td>
</tr>
<tr>
<td>6</td>
<td>White Canyon. Permian and Triassic rocks.</td>
<td>How is the Permian-Triassic unconformity expressed in White Canyon, and how did it form?</td>
<td>Construct schematic stratigraphic sections at three locations. Hang sections on a datum and correlate. Identify paletopographic relief and interpret its origin.</td>
</tr>
<tr>
<td>7</td>
<td>Shafer Trail, Canyonlands National Park. Triassic-Jurassic rocks.</td>
<td>What was the climate like in this area during the Triassic and Jurassic?</td>
<td>Construct schematic stratigraphic sections for Triassic through Jurassic strata. Interpret climate changes based on interpreted depositional environments.</td>
</tr>
<tr>
<td>9</td>
<td>Dinosaur track site located north of Moab, Utah. Jurassic rocks.</td>
<td>What was the size and speed of the dinosaurs that made these tracks?</td>
<td>Observe, sketch, and measure dinosaur tracks. Use empirical equations to estimate the size and speed of track makers. Test the equations using data from human tracks.</td>
</tr>
<tr>
<td>10</td>
<td>Green River Desert, north of Moab, Utah. Cretaceous rocks.</td>
<td>What was the paleogeography of this area during the Cretaceous?</td>
<td>Observe and collect marine fossils. Consult published correlated measured sections.</td>
</tr>
<tr>
<td>11</td>
<td>Capitol Reef National Monument. Permian-Triassic rocks.</td>
<td>What was the geography of eastern Utah like during the Permian and Triassic?</td>
<td>Each group observes, measures, and interprets a section. As a class, produce a fence diagram. Correlate fence diagram with data from Day 6. Construct paleogeographic maps. Contrast today’s results with those from Day 6.</td>
</tr>
<tr>
<td>12</td>
<td>Capitol Reef National Monument. Triassic-Cretaceous rocks.</td>
<td>How did climate and sea level change in eastern Utah from Permian to Cretaceous?</td>
<td>Each group consults published literature to obtain information about one formation. Examine rocks. Support or refute published material with field data. As a class, construct sea-level curves for this area during the Cretaceous.</td>
</tr>
<tr>
<td>13</td>
<td>Dinosaur National Monument. Pennsylvanian to Cretaceous rocks.</td>
<td>What steps are involved in constructing a geologic map?</td>
<td>Measure strike and dip, plot on topographic map. Identify formations and plot contacts on map. Construct geologic cross section.</td>
</tr>
<tr>
<td>14</td>
<td>Dinosaur National Monument. Pennsylvanian to Cretaceous rocks.</td>
<td>What is the Geologic history of this area?</td>
<td>Write a geologic report to accompany the geologic map and cross section. Use field data and published materials.</td>
</tr>
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Table 1. Itinerary and syllabus for the course.
used to work in their small groups to collect information in
the field and develop one or more hypotheses in response
to the unifying question. Near the end of the day particip-
ants returned to camp to discuss their ideas. On some
days, participants needed to consult published informa-
tion in the course's field library to develop and/or refine
their hypotheses. Materials in the field library included
maps, textbooks, professional publications, and popular
publications relevant to the course's topics.

At the end of each day, each participant was required
to compose a brief written summary of the day's activities
(including problem statement, methods, observations,
and interpretations sections). The summary explained the
ways in which all available data were used to develop a
hypothesis in response to the unifying question. The writ-
ten summary concluded with a discussion of the methods
and data that could be used to test the proposed hypothe-
sis. Following the philosophy of Popper (1966), students
were encouraged to identify ways in which their hypothe-
ses could be proven false, rather than supported. The in-
tstructors reviewed the written summaries each evening.

Grading – Instructors evaluated participant performance
mainly on the basis of the written summaries. Because the
course included participants from diverse backgrounds
(in-service teachers, pre-service teachers, and other stu-
dents) one might expect it to have been difficult to apply
uniform grading standards. The grades were assigned,
however, on the basis of how well each participant used
their own observations to develop their own hypotheses.
Answers were not wrong simply because they did not
conform to prevailing opinions. The research-oriented na-
ture of the unifying questions facilitated this approach be-
cause the questions focused on problems for which
solutions are debated among professional geologists. In
some cases the least geologically experienced participants
produced some of the best summaries. Perhaps the fact
that they were unencumbered by dogma and jargon al-
lowed them to see what really existed more clearly.

To ensure participants would not continue their ca-
reers as geologists and educators with a basic misunder-
standing of some feature or process, the instructors
summarized their own data and hypotheses (typically di-
vergent) before the start of the next field day. Group dis-
cussion was encouraged during and after the instructors'
presentations. Once participants realized there were many
possible responses to the questions posed, they were more
willing to develop their own ideas and spent less time
searching the field library for the "correct" answer.

One of the best aspects of the course's intensive for-
mat was that students got almost immediate feedback
about their work. Because participants were required to
turn in written materials each evening, common mistakes
or misunderstandings could be addressed the next morn-
ing and participants could immediately improve their
work. By focusing on how participants used data (their
own or that derived from published sources) to generate
hypotheses, the grading approach supported inquiry-
Based learning by encouraging students to consider new
mental models (e.g., Ireton et al., 1996). The grading en-
couraged creativity because it rewarded logical thinking
rather than memorization. Learning geoscience through
rote memorization of terms can be a very tedious process
(Holliday et al., 1996).

Journals and Self-Assessment - Participants were re-
quired to create an ongoing daily diagnostic learning log,
separate from their written technical summary, wherein
they assessed their own grasp of the material presented
during the day (Stanesco, 1991). The "journals" were ex-
tremely helpful because they gave participants a way to
influence the content and pace of the course. Instructors
reviewed the journals each evening. Whenever partici-
ants lacked understanding of material, the course’s itin-
erary was modified to allow time for additional practice.
The journals forced participants to reflect daily on what
they learned and/or were unsure about. The instructors
did not comment on the content of the journals unless a
question was directly posed.

Course Assessment - The daily journals served as one
of the tools used to assess the effectiveness of the course’s
overall design. Participants were also given a pre-course
and post-course exam that included questions designed to
measure lower-order and higher-order cognitive skills.
"Lower-order skills" include fundamental factual knowl-
edge, rudimentary understanding of basic principles, and
routine problem-solving abilities. "Higher-order skills"
include the ability to analyze, synthesize, and evaluate in-
formation. Attitudinal surveys that were packaged with
the pre- and post-course exams were used to measure
changes in student participants' feelings about geology,
problem solving, and the possibility of teaching as a ca-
reer.

Because course enrollment was limited, the sample
size used for initial assessment was small. In addition, the
participants were self-selected because students or teach-
ers who knew they would have been uncomfortable in
a field-based program simply did not register for the course.
While we will not do anything in the future to rectify the
self-selection bias, we will continue to assess future offer-
ings of the course to increase our sample size. We will also
monitor the long-term progress of student participants as
they complete their university courses and enter the
workforce. The longitudinal study will first match student
participants with non-participants that were of similar ac-
ademic rank, age, gender, and grade-point average prior
to the field course. Characteristics such as grade-point av-
verage and job satisfaction will be compared for partici-
ants and non-participants at regular intervals after the
field course.

Teaching Assistants – The teaching assistants for the
course were carefully chosen. The teaching assistants
played an important role in the education of participants
during the course so they needed to be competent, respon-
sible, and mature. In addition, they needed to have good
communication skills and the ability to be inclusive rather
than exclusive in their dealings with diverse groups of
people. We explained our teaching philosophy to pro-
spective teaching assistants, and we only considered those that were clearly able to understand our methods and goals. Teaching assistants were compensated with a tuition waiver and graduate stipend for the summer term.

Before the course began, the teaching assistants spent two weeks working with faculty to prepare for the course. They were expected to become familiar with the geologic problems investigated at each of the field sites. They were also expected to understand the pedagogy employed during the course. The teaching assistants were specifically taught not to answer a technical question with anything other than a different, carefully chosen question. For example, the question: “What mineral is this?” posed by a student to a teaching assistant would ideally have been answered: “Does it have cleavage?” “How hard is it?” “Is it transparent?” If participants could not answer these sorts of questions the teaching assistants would help the participants learn how to identify minerals on their own. The teaching assistants were also trained to give positive reinforcement to participants who made observations and developed interpretations on their own. While in the field, teaching assistants were instructed to ask specific questions at key outcrops to ensure participants made critical observations.

**Logistics** - Participants and instructors camped out during the entire course. Campsites ranged from completely undeveloped (no tables, no running water, no toilets) to well developed (electricity, showers, laundry, pizza delivery). Participants and instructors were organized into four-person cooking groups to prepare meals. The instructors planned the meals and did all shopping for the course; daily responsibility for meal preparation rotated through the groups. To minimize the amount of time spent packing and unpacking, we camped at each campsite for at least two nights.

**Recruiting** - We recruited students from our home university by directly contacting geoscience majors using email. We recruited middle school earth science teachers in our local area by making personal contact by mail and telephone. Our university’s Summer Programs Office, which runs several workshops and courses for teachers every summer, also recruited teachers. We sent information about our course to the National Park Service, the Utah Geological Association, the Geological Society of America, the Michigan Earth Science Teacher Association, and the National Earth Science Teacher Association. After the first offering of the course we ran a two-hour program for teachers at a local middle school. We also maintain a web site for the course that includes information about the course and downloadable application forms.

**Prerequisites** - Because we did not expect participants to have any prior geoscience experience, we had no prerequisites for the course. We specifically encouraged undergraduate students with backgrounds in geoscience or related fields to attend. Two of the participants were, however, scientific and technical communication (humanities) majors who learned of the course while working on our department’s website. Similarly, we actively recruited earth science teachers, but mathematics teachers became interested in the course because earth science provides a framework within which K-12 students more readily understand mathematical concepts.

**Group Dynamics** - Because our group consisted of a mix of students and teachers, we were initially concerned that the group would fractionate into sub-groups. While it did turn out that some participants were more comfortable working with certain other participants, these alliances were typically based on common interests, abilities, and energy levels, not on age or academic rank.

**Course Costs** - Financial support in the form of grants from the National Science Foundation, Copper Country Intermediate School District, Michigan Space Grant Consortium, and our home university made development of the course possible. Grant funds were used to develop activities at each of the field sites, establish a working relationship with National Park Service personnel, purchase camping equipment for participants to use during the course, purchase instructional materials, and provide partial scholarships to participants. In the future, participants will be charged a laboratory fee and tuition for the three-credit course. The tuition and laboratory fee will cover the cost of salary for two faculty and two teaching assistants, transportation in university vans between our university and Utah, transportation during the course, instructional materials, camping-related costs, and food. Our university worked with us to develop mechanisms that allow out-of-state in-service teachers to register for the course without being charged out-of-state tuition.

The participants kept some materials (e.g., grain-size charts, field books, course guidebooks) after completing the course. We retained other items (e.g., tents, camp stoves, compasses, Jacob staffs) for use during future offerings. We assumed that 10% of our equipment would need to be replaced after each course offering, and we included replacement costs in the course’s laboratory fee. The course’s tuition and fees were therefore set to ensure the course would be financially self-sustaining. The outside funding we received was required to initially develop the course and purchase equipment however.

**PEDAGOGICAL COMPONENTS AND EFFECTS**

Based on review of the National Science Education Standards, we identified eight pedagogical methods as appropriate for inclusion in this type of intensive, process-oriented, field-based course. Each of the components is described briefly in this section. Participant comments, excerpted from journals or post-course surveys, are presented in the rest of the paper in italics. The quoted material is shown as it was originally written, except minor grammatical or spelling errors are corrected and the names of participants are changed or excluded.

**Experiential Learning** - Work in the field gave participants a chance to become immersed in geology (Correll
and Bishop, 1997). It is difficult to consider a geologic feature as an isolated entity in the field because the interrelations between the feature under examination and the surrounding area must be addressed. One student commented at the end of the first day: “Seeing the evidence of roots, channels, and other stuff actually in the side of the butte (I think that’s what it’s called?) is much more real than looking at a sample in a classroom. You could really see how they fit into the larger picture.” After the fourth day the same student stated: “I am feeling quite overwhelmed by all the information we are covering.” The intensive nature of the course was trying at times for most students, particularly when physical discomforts made learning difficult. On the seventh day the student was again very positive: “I am learning so much! I’m really impressed with myself.”

**Hands-On Approach** – The course emphasized hands-on activities. New methods and information were taught only when needed. Because students often forget information presented well before it is applied, lectures were held to a minimum and used to present relevant background information only when necessary. The course was designed to keep participants active, whether collecting field data or consulting the literature to determine the results of prior research. At the end of the course one participant stated: “Taking this course further reinforced the importance of field experiences and “doing science” as opposed to just reading and memorizing science.”

**Group Learning** – During the course, participants worked in cooperative/collaborative groups of four or five. Ideally, each group included at least one professional teacher and a mix of experienced and inexperienced students. We anticipated that by encouraging in-service teachers and students to work together, the course would foster cooperative relationships between students and teachers. Small group formats also facilitate peer learning, where participants teach to and learn from each other (Dickinson and Hill, 1997; Rice-Snow, 1997). It is widely recognized that cooperative relationships enhance the learning experience for all (Johnson et al., 1994; Slavin, 1991), because each group brings a unique contribution and perspective to the course that benefits the group as a whole. The composition of the groups in our course was changed daily so participants got experience working with as many different people as possible.

An example of the cooperative, peer-learning that took place during the course is described in the following quote excerpted from the journal of a teacher participant. On the day he describes, participants were asked to measure dinosaur tracks in the field and to use empirical equations to determine the size and speed of the dinosaurs (Alexander, 1991). The participants were then asked to make their own tracks in a dry wash, calculate their speed using the equations they were given, and compare their calculated speed to their actual speed. The empirical equations did not accurately predict human running speeds, and participants were asked to develop new empirical equations using their data. “We measured dinosaur tracks and human tracks and tested the validity of the empirical formulas. This would be a great experiment for middle-school students. The math would be a bit too rigorous, however the data gathering would be right up their alley. I’m going to search for equations that are more reasonable for middle-school level students. Alison really impressed me today. Her math skills, patience and teaching ability are exceptional. Here it was 107° F and she was more than willing to help others with the math involving natural logs. I really appreciated it and I told her so.” In this example, the teacher led his small group during the data collection portion of the exercise. Later, when mathematical manipulation was required, a student participant took the lead. Both the teacher and the student ended the day knowing they helped their group achieve its goals.

**Intensive Instruction Modules** – Intensive instruction (one instructor working with four or five students) was used to teach new methods (e.g., topographic map interpretation, use of a Brunton compass, how to read a scientific article, how to take notes in the field, how to describe and classify rocks, how to write a scientific paper, etc.) and to ensure that material presented during lectures was fully understood. A small group format allowed the instructor to closely monitor participants’ progress. The small group format also allowed instructors to accommodate differences in learning styles and rates of learning encountered among the participants, and this aspect of intensive instruction facilitated the learning process for many. During intensive instruction, a single concept was addressed until all participants were able to demonstrate they understood it. A student’s comment at the end of the first day demonstrated that the small group, intensive instruction format was effective: “Wow! I am not sure everything that I was exposed to today actually registered in my brain, but I did learn quite a bit. Coming into this being completely clueless, I first felt intimidated. I was worried that everyone was going to be annoyed at all of my questions, but that is not how it turned out. Lenny [a T.A.] was the leader of the first group I was in. He really kept to the basics and by the end, I understood what was going on.”

**Problem Solving** – The unifying question posed to participants at the beginning of each day focused the day’s activities on answering a question. All of the activities conducted during the day were then relevant to the participants because they contributed information that could be used to develop their hypotheses. By providing a focus for activities, the open-ended questions motivated participants to do more than the minimum required; participants learned because they were interested, not because learning was required (National Research Council, 1996). As the course progressed, the questions that were posed required participants to consider how the material studied throughout the course was interrelated. As an example of the positive effect of successfully working through a problem, consider two comments made by one student with no prior geologic experience. She described her feelings after preparing her write up on the first day of the course: “After actually writing that out, I feel very frustrated. I also felt that way while trying to write it. I think it has to do with the fact that I’ve never been exposed to anything like this before, and it was
really hard for me to gather all of my thoughts on what we learned and try to make a paper out of them. I felt very unorganized and upset mainly because this is so different from anything I’m used to writing about.” After the second day of the course the same student reported: “Today things really kind of seemed to come together and make sense. Yesterday we talked about the mountains eroding to form the level Precambrian layer, but we didn’t know where the eroded material went. Today we saw some of the sediment and it really made sense to me. …I really didn’t feel very frustrated at the unifying question today because I can see the big picture now and fit it all together and sort of see what formed the area.” In this way, segmented observations gave way to broader conceptual understanding.

Development and Testing of Hypotheses — Throughout the course participants were required to generate hypotheses based on their own observations and their review of relevant literature. We required participants to develop their own explanations for what they observed by integrating different types of information acquired from a variety of sources (National Research Council, 1996). This process forced participants to conduct their activities with a hands-on, minds-on approach. They were continually considering how their activities provided information that could be used to test and refine their hypotheses. We encouraged participants to think about and question what was taught, rather than to passively receive the information and memorize it. One student’s comment shows that she enjoyed the creative aspects of science: “I love trying to picture what the climate was like years ago. Looking at the patterns and developing theories is so interesting. It makes me feel creative and scientific.” Our emphasis on doing science rather than just memorizing scientific information was reflected in the notes of several participants.

Participants gained confidence in their own abilities because they learned to develop and test ideas on their own. As the participants read materials in the field library, they realized that several of the publications contained contradictory explanations for things they observed in the field. In some cases, the participants were able to refute a published hypothesis with data that they themselves collected. After the initial shock of this discovery wore off, most students realized that they, just like “real, practicing scientists” were able to collect information that could be used to develop, support and refute hypotheses. They also learned to critically evaluate published materials and not believe everything they read.

Analytical Observational Activities — During the course, we encouraged participants to approach problems in a variety of ways. In some cases, and particularly for some participants, sketching field relationships prior to speculating about their origin was extremely helpful. We included this approach to demonstrate that researchers have many tools available to help them understand complex problems. For example, one exercise asked participants to sketch what they saw in the field before they were told anything about it. A pre-service teacher found the exercise quite helpful: “Sketching our entire field of view really was beneficial to me since I noticed much more detail than I probably would have otherwise. It made interpretation of the area a little easier because details about the landscape were already forming questions in my mind. Such as, why is this bed thinning out? Or, what’s causing the beds to dip in opposite directions?” In contrast, a participant who did not feel comfortable using art as an investigative tool reported: “It was good to get some practice at sketching, but I think a little more explanation about some of the features should have been included.” These comments highlight the fact that different individuals learn and are comfortable learning in different ways.

Communication Exercises — The course included daily writing assignments. Writing required participants to develop the cognitive skills required for analyzing data and presenting scientific information (Rice-Snow, 1997). Writing also helped participants to acquire and refine the technical skills necessary to convey information to others. The structure of the writing assignments forced participants to reflect upon each day’s activities and to consider successive information within the context of their previous work. Most of the participants’ comments included in this paper are taken from journals, and the comments demonstrate that the journals helped participants to actively consider their own progress as they learned new material.

GOALS AND ASSESSMENT

For our assessment plan, we adopted relevant assessment approaches outlined in the Teaching Goals Inventory (Angelo and Cross, 1993) and the National Science Education Standards (National Research Council, 1996). We defined our assessment purpose as evaluating the course’s effectiveness at achieving its goals (Table 2). An outcome-based approach was used to investigate the effectiveness of methods employed during the course (Chadwick, 1977; Orion et al., 1997).

Identical tests were used in the pre-course and post-course evaluation of lower-order and higher-order cognitive skills (Table 3). Although the repeat administration may have positively biased results on subsequent measures, we felt that we would have introduced more bias if we attempted to produce equally challenging alternate forms. Students received no feedback after initial administration.

About one-half of the questions on the pre-course and post-course exams were not directly addressed during the course. These items were included to assess whether conceptual development would transfer to different, but related, areas of scientific inquiry. We suspected that participants who were confident in their problem-solving abilities would be more likely to attempt to answer a question about which they had no prior knowledge than participants who were not confident in their abilities. In other words, we expected participants who had experience solving new problems on their own to attempt to reason through questions, even when they didn’t know the correct answer. At the end of the course one student complained: “A lot of the questions on the pre/post test aren’t covered in the course.” Another student stated that: “The
things I learned in this course are mostly things I can use every-
day or at least in the Houghton area. I don’t think this post-course survey reflects that information.” Both of these comments demonstrate our tests were designed to measure skills other than memorization. The comments also show that some participants were uncomfortable being given an exam for which they had not studied and memorized material in advance (although they were told that their responses would in no way influence their grade for the course).

RESULTS OF ASSESSMENT

Because only 16 participants took the pre-course exam and 15 took the post-course exam, our results do not support broad generalizations. The small sample size and the group’s heterogeneity (students and teachers) make it difficult to unambiguously interpret our data. The data do provide some encouragement that the course’s design contributed positively toward the course’s goals however. The results of our assessment of the course’s effectiveness at meeting each of its six specific goals (Table 2) are described below.

Technical Competence – Technical questions on the pre-course and post-course exams were designed to measure lower-order thinking skills (Table 3). Results of the pre-course and post-course technical exams (Figure 1) indicate that a slight increase in technical ability was achieved following the course. Although a few participants received slightly lower scores on the post-course exam than on the pre-course exam for individual questions, the group’s scores on the post-course exam were slightly higher or equal to the group’s pre-course scores on all but one question.

Problem-Solving Ability – Higher-order cognitive skills were tested using two open-ended, research-type questions (Table 3). Answers to these questions were generally longer and more detailed on the post-course exam than on the pre-course exam (Figure 2). This difference may be an artifact of the testing procedure (using identical questions on both the pre-course and post-course exams) or it may

Table 2. Outcomes and tools identified for assessment of the course.

<table>
<thead>
<tr>
<th>OUTCOMES</th>
<th>TOOLS</th>
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<tr>
<td><strong>Outcome I:</strong> As a result of this experience, participants will achieve an increase in their technical competence.</td>
<td>Pre-course/post-course instruments designed to measure “lower-order” (acquisition of basic knowledge, fundamental principles, and problem-solving algorithms) cognitive skills.</td>
</tr>
<tr>
<td><strong>Outcome II:</strong> As a result of this experience, students will know how to conduct research in a manner similar to professional researchers (i.e., making and recording observations, interpreting data, and consulting relevant published literature).</td>
<td>Primary trait analysis of diagnostic learning logs written in the field (evaluators: MTU faculty). Pre-course/post-course instruments designed to measure “higher-order” (analysis, synthesis, and evaluation) cognitive skills.</td>
</tr>
<tr>
<td><strong>Outcome IIIa:</strong> As a result of this experience, students will be more willing to tackle future intellectual challenges.</td>
<td>Pre-course/post-course attitudinal surveys (administered prior to the field program, just after the field program, post-baccalaureate and five years after graduation).</td>
</tr>
<tr>
<td><strong>Outcome IIIb:</strong> As a result of this experience, students will be better prepared to tackle future intellectual challenges.</td>
<td>Annual analysis of academic transcripts for participants v. matched non-field experience geoscience majors. Pre-course/post-course instruments designed to measure “higher-order” cognitive skills.</td>
</tr>
<tr>
<td><strong>Outcome IV:</strong> As a result of this experience, students will have a more positive attitude toward their disciplinary studies.</td>
<td>Pre-course/post-course attitudinal surveys (administered prior to the field program, just after the field program, and upon completion of baccalaureate study).</td>
</tr>
<tr>
<td><strong>Outcome V:</strong> As a result of this experience, students will be more likely to pursue a career teaching Earth science.</td>
<td>Pre-course/post-course attitudinal surveys. Survey of career choices (at graduation, two years after graduation and five years after graduation).</td>
</tr>
<tr>
<td><strong>Outcome VI:</strong> As a result of this experience, professional teachers will learn new ways in which hands-on activities that address diverse learning styles can be incorporated into K-12 classroom activities.</td>
<td>Analysis of diagnostic learning logs written in the field (evaluators: MTU faculty). Post-course interviews.</td>
</tr>
<tr>
<td>TARGET</td>
<td>SPECIFIC QUESTIONS</td>
</tr>
<tr>
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</tr>
</tbody>
</table>
| Lower-Order Cognitive Skills | • Describe how the geologist pictured should measure the thickness of the dipping rock layer using the Jacob staff. (Covered during course.)  
• What kind of fault is pictured here? Draw arrows on the diagram to show the direction of the fault’s movement. Does this type of fault reflect tension or compression in the horizontal axis parallel to the paper? (Covered during course.)  
• In what direction did the current that deposited this cross-bedded sandstone flow? Which way was up at the time of deposition? (Covered during course.)  
• How are global sea level and climate affected by the waxing and waning of high-latitude glaciers? (Covered during course.)  
• Why are evaporite basins often associated with hydrocarbon accumulations? (Covered during course.)  
• For a given region, what are the main factors that determine the rates of physical and chemical erosion? (Not covered during course.)  
• What factors dictate the preservation and formation of petroleum reservoirs? (Covered during course.)  
• What factors affect the flow of water in the subsurface? (Not covered during course.)  
• What effects does channelization (the artificial straightening and widening of a river channel) have on downstream areas during times of high flow? (Not covered during course.)  
• What evidence is there that the Earth is very old? (Covered during course.)  
• What are the differences between continental and oceanic crust and how are these differences demonstrated during collision of plates whose colliding margins are composed of these two types of materials? (Not covered during course.) |
| Higher-Order Cognitive Skills | • Many scientists suspect that the Earth is now experiencing global warming. If you were asked to study this phenomenon (that is, determine whether or not warming is occurring and estimate the extent of warming that is likely to occur within the next one hundred years) please describe the steps that would need to be taken to conduct a successful research program. (Not covered during course.)  
• Is there life on other planets? At present, we don’t know and it is unlikely that we will obtain any direct evidence of life on another planet in the near future. Your answer should be based on probabilities, inferences, and logic. What steps would you take to investigate the question? (Not covered during course.) |
| Pre-Course Attitudinal Survey | • How would you describe your current level of interest in the study of geology? What factors or aspects of the study of geology do you find most interesting?  
• What factors or aspects of geology do you find most uninteresting?  
• Which of the following teaching methods positively influence your learning?  
• I am generally interested in tackling new intellectual challenges.  
• Do you feel confident in your ability to solve new or difficult problems?  
• If you are not currently a teacher, how likely are you to pursue a teaching career?  
• If you are currently a teacher, was a field-based course beneficial to you during your undergraduate career?  
• If you are “somewhat likely” or “very likely” to become a teacher, how likely is it that you will pursue a teaching career in earth science? |
| Post-Course Attitudinal Survey | • How did your level of interest in the study of geology change as a result of taking this course?  
• What factors or aspects of the study of geology do you find most interesting?  
• What factors or aspects of geology do you find most uninteresting?  
• Which of the following teaching methods positively influence your learning?  
• How did the course change your level of interest in tackling new intellectual challenges?  
• How did the course change your level of confidence in your ability to solve new or difficult problems?  
• If you are not currently a teacher, how likely are you to pursue a teaching career?  
• If you are currently a teacher, was this field-based course beneficial to you?  
• If you are “somewhat likely” or very likely to become a teacher, how likely is it that you will pursue a teaching career in earth science? |

Table 3. Questions from Pre-Course and Post-Course Assessment Exams.
reflect an increase in the participants’ willingness to work through difficult problems.

**Problem-Solving Interest and Confidence** – The higher-order cognitive skills exams (Table 3, Figure 2) were coupled with the results of the pre-course and post-course attitudinal surveys (Table 3, Figure 3) to measure the participants’ level of interest and confidence in their own ability to solve problems. The answers to the post-course higher-order cognitive skills questions were longer and more detailed than answers given to the same questions on the pre-course exam. Results of the attitudinal surveys indicated participants were generally interested in tackling new intellectual challenges and were confident of their ability to solve new or difficult problems prior to the course. Participants did however feel that their interest in new intellectual challenges and their confidence in their ability to solve new or difficult problems increased as a result of taking the course.

**Disciplinary Interest** – The results of the attitudinal surveys (Figure 4) show that the self-selected participants in the course were somewhat interested or very interested in geology prior to taking the course. As a result of taking the course, most felt that their level of interest in geology (although initially high) increased.

**Career Choice** – After the course, the number of students indicating it was very likely or somewhat likely they would pursue a teaching career increased from five to eight. Two fewer students indicated on the career choice survey it was very unlikely or somewhat unlikely that they would pursue teaching as a career (Figure 5). During the fall quarter following the course, one student changed her major from geology to earth science education. Her experiences during the course influenced her decision. A pre-service teacher established a strong connection with a teacher during the course and is now doing his student teaching with that teacher. This pre-service/in-service teacher team also traveled back to Utah during the fall of 1999 to collect additional information and samples to use in their classrooms. The course may have increased the likelihood that student participants will pursue a teaching career. In addition, the course helped pre-service and in-service teachers become acquainted and develop relationships that were beneficial to both parties during and after the course.

**Teaching Methods** – Teachers were exposed to new methods during the course that could be applied in their own classrooms. For example, on the day in which sketching was employed to stimulate analytical observational skills (described in the Pedagogical Components section), a teacher recognized that we were trying to accommodate diverse learning styles and stated: “Our diagrams ranged from good to crude yet most of them clearly pointed out what could be the sinking of an anticline. Students that are artistic would be very excited about this type of activity. It made me think of the 4-5 students in my classroom that seem to frequently doodle and draw as though they had to.” Similarly, the teacher recognized that the observations and mathematical analysis of dinosaur trackways (also described in the Pedagogical Components section) would intrigue his middle-school students.

Participants were queried about the effectiveness of several types of teaching methods (e.g., the use of lectures, demonstrations, hands-on exercises, and field studies) prior to and following the course (Figure 6). Participants were asked to comment on the effectiveness of the unifying questions only after the course. The number of partici-
pants who felt that all of the specific types of teaching methods positively influence learning increased slightly after the course. The small magnitude of increase, coupled with the small sample size makes this result insignificant. Only one-third of the participants felt unifying questions positively influenced learning. We, the instructors, feel the unifying questions did positively influence learning. We suspect that the participants did not find them particularly helpful because they lacked the perspective to see how the unifying questions helped them to integrate diverse material during the course. In the future we will spend more course time focusing on how the unifying questions are related to one another and how the answers to the unifying questions form a foundation upon which participants can frame relatively far-reaching interpretations about Earth processes and history. No student was less interested in field-based activities following the course, despite the heat, altitude, and insects that plagued the course at times.

We have used the methods employed during the course to develop activities for K-12 students. For example, 4th graders in Virginia were shown slides of dinosaur trackways and reconstructions of different types of dinosaurs. Models of theropod (meat-eating dinosaurs) feet were then used by the 4th graders to determine the importance of substrate on the preservation of tracks. The students were encouraged to investigate the ways in which the speed and size of organisms can be inferred from tracks by comparing trackways made by different members of the class when they ran or walked through sand. Students in the test classroom all grasped the concept that tracks can be used to indicate behavior, and that the pres-

Figure 3. Problem solving interest and confidence. A) Level of participants' interest in tackling new intellectual challenges prior to the course. B) Change in level of interest in tackling new intellectual challenges following the course. C) Level of participants' confidence in their ability to solve problems prior to the course. D) Change in level of confidence following the course.

Figure 4. Interest in disciplinary studies. A) Level of participants' interest in the study of geology prior to the course. B) Level of participants' interest in the study of geology following the course.
ence of tracks is controlled in part by the environment of deposition.

**Participant Comments** — At the end of the course, participants were asked to make comments about the course. Although some comments were included earlier in this section, others follow. A junior-level student stated: “This was probably the most interesting course I have ever taken.” A freshman offered: “…I learned more geology in two weeks than I did in my first year.” One of the non-majors in the course summed up her impressions: “My background in geology going into the class was zilch! To get to the point where I could write two pages of geological theory with phrases that I understood was such a boost for my confidence. I feel semi-scientifically knowledgeable, and I used skills I hadn’t practiced in a while and thought I had lost. THANK-YOU!”

One student clearly expressed dissatisfaction with the open-ended nature of the unifying questions posed during the course. On the post-course exam, participants were asked: “What aspect of geology do you find most uninteresting?” The student answered: “Nothing is certain.” On the same theme, another student stated: “The only thing that could have been improved was the organization of the class. Too much time was spent guessing what was going to happen next and what was to be done.” The course required many students to consider the learning process in a new way, and some were not comfortable working without clear and precise direction. We, the instructors, learned that our goals were not always clear, and the students often had a hard time interpreting what we expected from them. In the future we will clarify assignments and try to reduce some anxiety by continually reminding participants that their grades are based on how they arrive at their answers rather than the answers themselves.

**CONCLUSIONS**

Abundant literature exists on the positive effects of field experiences, but few studies attempt to quantify benefits. The results of our assessment cannot be interpreted with absolute confidence due to small sample size and mixture of participant types (students and teachers). Despite problems with the sample, the data collected suggest the field course had an immediate, measurable positive impact on its participants. The mechanisms for assessment consisted of quantitative test scores, attitudinal surveys, and diagnostic learning logs. These indicate the course produced an increase in participants’ level of competence and interest in geoscience. Most participants felt that the course helped them to understand geology in particular as well as science in general. The intensive nature of the course, supported by the geologic exposures of southeastern Utah created an environment conducive to motivated, focused learning. Some participants were frustrated during the course because of its emphasis on open-ended questions that could be answered in a variety of ways. These questions, however, helped the instructors facilitate development of participants’ problem-solving abilities. Although the problems did not get easier as the course progressed, the participants became increasingly adept at using any and all available information to figure things out on their own.

Our targeted mix of teachers and students promoted the concept of teaching as a career. Both the teachers and...
the students benefited from the content of the course. Teachers gained experience with nontraditional teaching techniques and learned new ways in which hands-on activities could be performed in the classroom. Pre-service teacher participants in the course formed connections with professional teachers that continue to contribute to their professional development.

The undergraduate students who participated are motivated and active in their departments. Some are involved with research projects directed by faculty members. Connections established among participating students during the course fostered a sense of cooperation that continues as the students move through their disciplinary studies. In contrast to the traditional capstone field experience, students were encouraged to take this course during their freshman or sophomore years. The friendships established during the course promoted cooperative learning arrangements that will help the students throughout their undergraduate careers.

This course was as rewarding and exhausting for the instructors as for the participants. Just as the students were asked to learn in new ways, the instructors were forced to teach in new ways. That was a challenge, but the positive effects of the new methods were undeniable, and many aspects of this course are currently being incorporated into the instructors’ classroom teaching. The course has become a standard offering within our department.

The elements of this course are currently being incorporated into a CD-ROM-based educational tool. A short video, an instructor’s manual, a student workbook, and a rock-sample kit will accompany the CD-ROM. These materials are designed to bring the field experience and pedagogical approaches employed during the course into lower-division university courses. Our goal in developing these materials is to demonstrate to students at the onset of their university careers the interrelations between geological processes and effects. The materials are intended to provide a framework in which subsequent courses will seem more relevant to students because they will have the perspective necessary to see how individual courses contribute to a holistic geoscience education.

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Phenomena are arranged in chains of necessary sequence. In such a chain each link is the necessary consequent of that which precedes, and the necessary antecedent of that which follows...Antecedent and consequent relations are therefore not merely linear, but constitute a plexus; and this plexus pervades nature.