# Increasing Expertise in Earth Science Education through Master's Education

Jackie Huntoon[1,a] and Brad Baltensperger[2]

## ABSTRACT

The processes of developing and the results of testing a master's degree program designed to increase the number and quality of secondary-level earth science teachers are described in this paper. The master's program is intended to serve practicing secondary-level science and math teachers who lack subject-area endorsement in earth science. There is need for programs such as this because there is a nationwide shortage of qualified earth science teachers. By targeting teachers who are already trained and certified in science or math, the program can focus solely on earth science content and pedagogical content knowledge. The program can be completed in 2 y via online academic-year instruction and on-campus or field-based training during summers. Completion of the master's program satisfies teachers' need for ongoing professional development. A group of teachers pilot-tested the master's curriculum and participated in qualitative and quantitative evaluation activities. The program is recognized by the state of Michigan as a path to subject-area endorsement in earth science. All materials developed for the program are available online and will be made available to others who wish to use it as a model for development of similar programs. © *2012 National Association of Geoscience Teachers*. [DOI: 10.5408/11-224.1]

*Key words:* teacher preparation, master's education, evaluation and assessment

## INTRODUCTION

Students enrolled in earth science courses are frequently taught by teachers who lack in-depth training and/or certification in the field. This is problematic because there is a growing body of evidence that teachers' proficiency with the content they are teaching is strongly correlated with student outcomes (e.g., Blank and Toye, 2007, and references cited on their p. 2). All of the sciences suffer to some degree from inadequate teacher preparation. Although data regarding the level of teacher preparation is spotty, data collected over the last decade suggest that the situation in earth/space science is particularly serious. In 2007, for example, only 77% of science teachers nationwide possessed a college major in any science, although those teachers were not necessarily teaching the same science as their college major (Blank and Toye, 2007). Only 35.5% of earth science teachers in public high schools had a college major in a geoscience discipline in 1999–2000 (Seastrom et al., 2002 [revised 2004]). Earth science teachers are the least likely of all science teachers to be certified in their teaching field: 28% of earth science teachers lacked certification in 2006 (National Science Board, 2006). By contrast, only 17% of biology teachers were not certified to teach their subject during the same year (National Science Board, 2006).

Although weak content-area preparation of earth science teachers is an important concern, an even more significant issue may be the fact that most high-school students never take an earth science course. Only 17.4% of public and private high-school graduates took a course in geology or earth science in 2000 (National Center for Education Statistics, 2009, table 151). This compares unfavorably with the fact that 91.2% of graduates took biology, 66.2% took chemistry, and 31.4% took physics during the same year (National Center for Education Statistics, 2009, table 151). Many students are unable to take earth science courses because their schools do not offer the subject due to a lack of qualified teachers (Geary et al., 2005).

Secondary-level science curricula tend to emphasize physics, chemistry, and biology throughout the United States. Michigan, for example, requires students to complete three secondary-level science courses prior to graduation from high school: biology, plus either chemistry or physics, plus one additional science course. Students can take biology, chemistry, and physics and satisfy the state's requirement. Therefore, most schools feel compelled to offer these three subjects (physics, chemistry, and biology) at the high-school level because these are specifically identified in the state's requirements. Biology, chemistry, and physics are given priority, whereas earth science courses are only offered if there are resources (teachers, space, materials) available after the priority sciences have been scheduled.

In Michigan, the window available for high-school science instruction is compressed, as all students are given their final high-stakes test in the eleventh grade. This means that students must complete all of their basic science courses prior to or during the eleventh grade. Because of their priority status, biology, chemistry, and physics are typically taught in grades 9–11, and earth science is taught in the eighth grade, if it is taught at all.

When earth science is offered in the eighth grade, it can be taught by teachers with elementary-level certification. In Michigan, elementary certification covers all subjects in grades K–5. Elementary teachers can also teach specific subjects in grades 6–8 if they hold an appropriate content-area endorsement (Michigan Department of Education,

*Received 22 February 2011; revised 8 October 2011; accepted 27 January 2012; published online 13 June 2012.*

[1]Graduate School and Department of Geological and Mining Engineering and Sciences, Michigan Technological University, Houghton, Michigan 49931, USA

[2]Department of Cognitive and Learning Sciences, Michigan Technological University, Houghton, Michigan 49931, USA

[a]Author to whom correspondence should be addressed. Electronic mail: jeh@mtu.edu

 

2011). Teachers with elementary certification are considered qualified to teach eighth grade earth science if they possess subject-area endorsement in integrated science, general science, or earth science. Integrated science (known in Michigan as DI) is the most popular elementary science endorsement. The general science endorsement is no longer offered by the Michigan Department of Education, and the earth/space science endorsement only prepares teachers to teach earth/space science. Elementary teachers with DI endorsement can teach biology, chemistry, physics, and earth/space science in grades 6–8, as well as integrated science in grades K–5. To be eligible for DI endorsement, teachers must earn at least 24 college-level credits distributed across the broad areas of life, physical, and earth/space science. This means that elementary teachers with DI endorsement may have as few as 8 credits of college-level earth science training (approximately 2–3 courses).

Secondary certification in Michigan covers grades 6–12 (Michigan Department of Education, 2011). As at the elementary level, the secondary-level integrated science (DI) endorsement is popular because it allows teachers to teach biology, chemistry, physics, and earth/space science (in grades 6–12). In contrast, the earth/space science endorsement only prepares teachers to teach earth/space science. Secondary-level teachers with the DI endorsement are highly sought by school districts because they can be assigned to almost any science course. As at the elementary level, secondary-level teachers with the DI endorsement may have as few as 2–3 college courses in earth science.

The situation in Michigan is not unusual. There is a nationwide shortage of qualified science teachers (Ingersoll and Perda, 2009) that is negatively affecting earth science instruction in many states. Although most practicing earth science teachers are legally considered to be "highly qualified" (because they are teaching within the limits of their certification), many lack in-depth training and subject-area endorsement in earth science. Geoscientists and others are concerned about this issue because the quality of the future science workforce depends, in part, on the quality of science education available to students today. It has been repeatedly shown that students are most likely to succeed if their teachers possess strong content-area preparation (Glenn Commission, 2000; Coble and Allen, 2005). Teachers with strong content-area training have the depth and breadth of knowledge that make it possible for them to use laboratory and/or field experiences to involve students in the process of doing science, as recommended by Singer et al. (2005), rather than just learning about science. Teacher education programs that provide teachers with the content-area knowledge as well as the pedagogical content knowledge (Shulman, 1986) required for successful instruction are key to the continued strength of the geoscience workforce.

Across the country numerous efforts are under way to improve teachers' preparation and increase students' exposure to geoscience. Many examples of these efforts have been described in the *Journal of Geoscience Education* and elsewhere. The program described in this paper is similar to those at Eastern Michigan University (Rutherford, 2008), Mississippi State University (2010), and Penn State (2011) in that it focuses on education for in-service teachers at the graduate level. It is similar to the Mississippi State program in that it incorporates both online and face-to-face instruction and does not require prior training in geoscience.

The program described in this paper may serve as a useful model of a strategy to increase the number of well-trained earth science teachers because it leverages existing teachers' prior training. Increasing the size of the earth science teacher workforce will make it possible for more districts and schools to offer earth science classes at the secondary level. Earth science teachers working in the schools have the potential to influence the courses that are offered at different grade levels. Like others involved with earth science teacher education, we hope that growth in the size of the teacher workforce will lead to an increase in the number of earth science courses taught and the number of students taking earth science courses.

## DEVELOPING A MASTER'S PROGRAM LEADING TO ENDORSEMENT

A strong collaboration between a geoscience department (Geological and Mining Engineering and Sciences) and an education department (Cognitive and Learning Sciences) was critical to developing the master's program. At Michigan Tech, these two departments have collaborated in the past to develop and test numerous professional development programs for teachers. They also jointly developed an innovative preservice teacher education program that results in students earning a bachelor of science (BS) degree in geology while satisfying state requirements for secondary-level teachers of earth science. The BS program was designed to prepare highly qualified teachers while at the same time providing students with the background needed to enter the geoscience workforce and/or graduate school. It was used as a model during the planning of the master's (MS) program.

### Designing the Master's Curriculum

The most important consideration in developing the MS program was that it needed to completely satisfy all of the state's requirements for subject-area endorsement in earth/space science. The MS program was developed using a backwards design process (Wiggins and McTighe, 2005) so that the state's requirements were explicitly addressed by one or multiple components of the curriculum.

The state of Michigan requires programs to demonstrate full alignment with the "Michigan Standards for Teacher Preparation" prior to being recognized as a path to subject-area endorsement. We felt that the curriculum should prepare teachers to pass the subject-area endorsement test in earth/space science as well as to teach earth science content effectively. Therefore, we designed the curriculum so that it would address all of the state's High School Content Expectations (HSCEs) for earth/space science. The Michigan teacher preparation standards are not exactly aligned with the HSCEs because the teacher preparation standards were adopted prior to development of the HSCEs and have not yet been revised.

Michigan divides the HSCEs into four categories: prerequisite knowledge (should be covered prior to high school), essential knowledge (useful for all high-school students and assessable via the high-stakes Michigan Merit Exam or MME), core knowledge (useful and required for receipt of high-school credit in the subject), and recom-

**TABLE I: Components of the master's degree program.**

| Course Title and Description | Course Number | Semester Hours |
|---|---|---|
| Earth System Science I: Basic geologic content traditionally covered in university-level physical geology and historical geology. The course takes a place-based approach using the geologic record of Michigan. | GE5020 | 4 |
| Earth System Science II: Focuses on material traditionally covered in courses on astronomy, meteorology, and oceanography. This course integrates material by focusing on Earth's climate system. | GE5030 | 4 |
| Geology of Utah's National Parks: Two-week, field-based course. Earth system approach used to determine processes (tectonics, sea-level change, climate change, etc.) responsible for development of rocks and landforms. | GE5130 | 4 |
| Engineering Applications in Earth Science: Problem-based course demonstrates how engineers use principles from the earth sciences to solve problems and design systems. | ENG5300 | 4 |
| Natural Hazards and Human Impacts: Interaction of humans and the environment is examined through field study in the Upper Peninsula of Michigan. | SS5150 | 3 |
| Graduate Research in Geology: Research of an acceptable geological engineering, mining engineering, geology, or geophysics problem and preparation of a report. | GE5999 | 2 |
| Science Education Research: In-depth study of education research methods pertaining to classroom practice, curriculum standards, and program evaluation. | ED5700 | 2 |
| Science Learning Materials, Inquiry, and Assessment: Examination of learning materials that support inquiry-based learning. Study of alternative and authentic assessment techniques for evaluating science learning. | ED5730 | 2 |
| Connecting Michigan Science Benchmarks and Research: Current research and classroom practice are examined using Michigan Science Benchmarks with the objective of understanding how goals promote higher levels of learning. | ED5740 | 2 |
| Electives | – | 3 or more credits |
| **TOTAL** | | 30 credits minimum |

mended knowledge (useful but not required for graduation credit). The HSCEs are grouped into a series of content statements that are in turn grouped within a set of five content standards.

The MS program was designed to prepare teachers to teach content assigned to both the essential and core knowledge HSCEs, because both categories of HSCEs must be covered in courses offered for high-school science credit. Two of the courses (ESS I and ESS II) developed as part of the MS curriculum address all HSCE categories (prerequisite, essential, core, and recommended). Teachers who take these courses should be familiar with material their students study in the primary grades and have the opportunity to learn more about in advanced high-school or college-level courses. Teachers who know more about a subject than what they are required to teach are more confident of their ability to teach a subject well (Kind, 2009).

We were fortunate to be able to develop and offer the MS program under the umbrella of an existing degree program in applied science education at Michigan Tech (Michigan Technological University Division of Teacher Education, 2007). Therefore, we did not have to propose a new degree program and have it approved by the university and the state. The applied science education MS program at Michigan Tech serves practicing teachers who already possess a bachelor's degree and secondary certification. It emphasizes rigor in the content areas and allows for the development of specialized curriculum tracks that prepare teachers for endorsement in a specific discipline. Like the undergraduate teacher education program, the MS program depends on strong collaboration between content-area and teacher-education faculty members.

Ultimately, it was determined that the required content could successfully be addressed with a 30-credit MS program (Table I) that included three new courses. By integrating concepts across traditional course boundaries, these innovative courses cover content that is addressed in a total of seven to nine courses in a traditional undergraduate curriculum. Rather than teach concepts in isolation, these courses take a problem-based approach, allowing for in-depth study of key topics within the framework of authentic problems (Massa, 2008; Pepper, 2009). These courses require extensive amounts of self-motivation, out-of-class preparation, critical thinking, and reflection. They do not focus on developing basic knowledge in science but rather on applying knowledge and skills to earth/space science problems. Because these courses assume mastery of concepts typically acquired by science teachers at the undergraduate level, they are appropriately offered at the graduate level.

The three new courses are briefly described here because the state of Michigan has approved them as replacements for the larger set of courses required for completion of the undergraduate preservice teacher preparation program. This is a clear example of a situation where individual courses with a relatively narrow and specific focus are not necessarily needed in order to cover topics required by accreditation and review organizations.

Two of the new courses, Earth System Science I and Earth System Science II (ESS I and ESS II), are taught online during the academic year. A tenured faculty member serves as the instructor of record and oversees the course. Day-to-day course management and recitation-type interactions are led by a doctoral student who serves as a teaching assistant. The assistance provided by the graduate student is a key factor in making the course possible, as hurdles encountered by online learners can be varied and complex. Both the faculty member and the teachers in the course appreciate having access to an individual who understands the geoscience content and is able to quickly troubleshoot technology-related problems.

Each course requires teachers to watch short "mini-lectures" online one to three times per week. These short lectures are designed to promote reflection on how other course activities relate to key topics (Means et al., 2009). The lectures are designed to stimulate interest in topics, demonstrate the relevance of those topics to teachers' and their students' lives, and relate new topics to those covered earlier in the course and to those that will be covered subsequently. After watching the lectures, teachers read assigned materials, work through problems or exercises that are available online from a variety of sources, and participate as a group in chat sessions with the instructor. To ensure that everyone is keeping up, a short quiz is given each week based on the reading assignments. The quiz provides a grading incentive to ensure that assigned readings are completed on time. The texts that are assigned and recommended for the two courses cover material at a variety of levels and from multiple perspectives. Each course also requires completion of a final project that requires integration of information from throughout the course. Some projects are prepared in the form of an inquiry-based lesson plan. The courses emphasize the importance of demonstrating the relevance of information. Teachers are encouraged to take a place-based approach in their own teaching by making use of features or problems near their home schools.

ESS I includes geologic content traditionally covered in university-level physical geology and historical geology courses. This course uses the geologic record of Michigan to provide concrete examples of the products of processes that operated in the past or are currently acting on the region. Much of the rock record in Michigan is sedimentary in origin and contains a record of changes in paleogeography and life through time. The course uses the sedimentary rocks in the Michigan basin to demonstrate how scientists determine the origin and age of the rocks, and where, how, why, and when some areas were uplifted while others subsided. The course includes a semester-long "life journal" project in which teachers keep track of the changes in life through time on Earth and in the state's rock record.

ESS II presents material traditionally covered in introductory courses in astronomy, meteorology, and oceanography by focusing on Earth's climate system. The course investigates long- and short-term climate change, as well as the data that are used by scientists to document past climate change and predict future changes. A variety of data sources are used during the course, including ice-core data from the Greenland and Antarctic ice sheets, deep-sea drilling data, meteorological measurements from sites such as Mauna Loa, and astronomical parameters available from the U.S. Naval Observatory and other sources. Through the use of large real-time, near real-time, and long-term data sets, teachers have the opportunity to become familiar with a variety of techniques and tools. The capstone project for this course is development of a new lesson plan on climate or weather that is specifically tied to teachers' local areas.

The third new course, Natural Hazards and Human Impacts, is taught in the field in the western Upper Peninsula of Michigan during the summer. The course presents examples of natural hazards and their effects on human populations throughout the world. Michigan Tech is located on the Keweenaw Peninsula, which hosts the world's largest native copper deposits. The copper is found in approximately 1.1 Ga volcanic and sedimentary rocks, which were unearthed during Pleistocene glaciation and mined by the region's inhabitants until the end of the 20th century. Examples of potential hazards in the area include true "natural" hazards as well as those resulting from human activities. The course emphasizes the interplay between societal development and the Earth system. Glacial deposits are common in the region and provide excellent evidence of the effects of long-term global climate change. Laboratory and classroom-based activities supplement field experiences during the course. This course satisfies the state's requirement for social science content and reinforces the relevance of the geosciences by providing strong social context for content that is commonly included in environmental geology or natural hazards courses. Teachers who take this summer course live in the university dormitories.

## EVALUATION OF THE MASTER'S PROGRAM

The major goal for developing the MS program was to increase the number of teachers qualified to teach earth/space science. To determine the success of the MS program at meeting this goal, it was formally evaluated. The content of the two online courses was reviewed by a master earth science teacher. A group of nine teacher-students pilot tested the first online course during its initial offering. A cohort of seven teacher-students pilot tested the MS program as a whole. All of the pilot-testers were practicing teachers who were already certified to teach math or science at the secondary level. All possessed a math or science endorsement before starting the program. Of the seven teachers who pilot-tested the entire program, five had biology endorsements, three had general science endorsements, one had a chemistry endorsement, and one had an earth/space science endorsement prior to the program. The teachers who pilot tested the courses and program participated in quantitative and qualitative evaluation activities. The final part of the program evaluation was conducted by the state of Michigan when it completed its review of the program prior to approving it as a path to subject-area endorsement in earth/space science.

The pilot cohort of teachers began working toward their MS degrees in 2007. As of September 2011, three teachers had completed the MS. Four teachers were nearing completion; three only needed to complete and defend their final research project in order to graduate. Since the program was first offered, many other teachers have taken one or both of the online courses. One of those successfully passed the test for teacher certification in earth/space science in another state after completing the online courses, suggesting that the course content is appropriate for training teachers in states other than Michigan.

**TABLE II: Course evaluation questions.**

| Questions |
|---|
| 1. Does the course material align well with the standards? The standards to be met by each course are included in the syllabi. We are particularly interested to know your thoughts about the completeness of content coverage. |
| 2. Are the courses and their delivery sufficiently innovative that they could serve as models for an alternative way to deliver essential earth science content? |
| 3. Based on your experience as a teacher, is there anything that is overemphasized or underemphasized? |
| 4. Is the delivery model—short lectures with more time for teacher-students to investigate concepts on their own—a valuable approach, or are there significant problems with this approach? |
| 5. We would ordinarily expect a four-credit graduate course to require about 12–16 hours of work per week. Is this the approximate workload expectation for these courses? |
| 6. Should the courses be restructured as two-year-long offerings, with less time required per week? |
| 7. Will you feel confident to integrate earth science concepts or examples into your science courses or to teach an earth science course? |
| 8. Will you be more comfortable integrating technology into your instructional practice as a result of taking these two courses? |

Due to the small size of the pilot cohort, demographic data (gender, race/ethnicity) cannot be provided here. The Institutional Review Board that oversaw the project does not allow these data to be reported when fewer than ten individuals fall into any single category.

## Evaluation of the Online Courses Developed for the Master's Program

After the first online course was taught (ESS I), the master teacher reviewed the syllabus, textbooks, homework assignments, and mini-lectures for the course and was asked to respond to a series of questions (Table II). The master teacher also reviewed all materials planned for use in the second online course (ESS II).

In order to determine the effectiveness of the instructional approach in the online Earth systems courses, the first nine teachers to take the course were invited to participate in pre- and postcourse testing. Items on the tests were developed by a geology PhD student and reviewed and revised (when necessary) by a geology faculty member. The subject matter addressed by the questions in the first two sections of the test (content-area and critical-thinking questions in Table III) was based on the Michigan HSCEs. The questions in the second two sections of the test (Likert-scale questions in Table III and attitudinal questions in Table IV) were designed to obtain information related to teachers' confidence, classroom practice, career plans, and attitudes toward online learning opportunities. The tests were intended to gauge teachers' learning of earth/space science content and their attitudes toward teaching the subject and participating in the MS program.

The teachers were divided into two groups for testing purposes. The first group completed one version of the pre/post-test prior to the start of the course and later completed a second version of the pre/post-test at the end of the course. The second group took the tests in the opposite order. This was done to reduce the likelihood of repeat-administration bias. Questions on the two tests were paired so that each test addressed the same content; that is, question 1 on test "A" (Table III) addressed the same basic concept as question 1 on test "B." Tests were coded before they were scored so that the pre- and postcourse tests were indistinguishable to the scorer. Tests were scored by two geology PhD students, and the scores were reviewed by a geology faculty member. In no case did the two scorers differ in their rating of an individual item by more than one point.

The questions fell into four basic categories. The first were content-area questions (Table III) that were used to determine whether the teacher-students showed any gains in knowledge about the content covered in the course. A rubric was used to guide the scoring (blank = 0; wrote something irrelevant = 1; seems to have heard terms before but does not answer reasonably = 2; reasonable = 3; correct = 4).

The second set of questions (critical thinking) was intended to measure reasoning, creativity, and integrative thinking. These answers were also scored using a rubric (blank = 0; short answer, no justification given = 1; reasonable answer with justification given = 2). The length of the answers (word count) was also recorded.

The third set of questions (Likert scale) focused on classroom practice and attitudes using a Likert scale. The Likert-scale questions were identical on all tests (both versions). For the first 10 questions, the five-point scale ranged from strongly disagree, far inferior, or not at all confident on the left-hand side through neutral or unsure in the center to strongly agree, far superior, or very confident on the right-hand side. "Not applicable" was also a possible answer, and respondents were allowed to skip questions they preferred to not answer. The last three questions each had unique sets of possible responses (Table III).

The final set of questions (attitudinal, Table IV) was intended to measure participants' perceptions regarding the course and its effects. These constructed-response questions were identical on both versions (A and B) of the precourse tests and on both versions (A and B) of the postcourse tests. The questions asked before the course (precourse) differed from those asked after the course (postcourse), however.

## Results of Evaluation of the Online Courses

The master teacher's assessment of the online courses was positive overall. He stated: "These courses are an excellent vehicle by which teachers lacking a solid foundation in the earth/space sciences may improve both their content knowledge in the subject and develop effective ways in which to deliver it." He expressed some concern that the teacher-students were not sufficiently proficient with technology at the start of the first course and that he would like to see additional opportunities to use technology integrated

**TABLE III: Sample pre- and postcourse questions for ESS I.**

| Sample Test "A" Content-Area Questions | Sample Test "B" Content-Area Questions |
|---|---|
| 1. Earth's moon was most likely formed by? | 2. How did cyanobacteria alter the early atmosphere? |
| 3. How do we know that the outer core is liquid? | 4. Why isn't glass (even naturally formed glass) a mineral? |
| 5. What is the principle of stratigraphic superposition? | 6. How is an earthquake's focus different than its epicenter? |
| 7. Basalt is (low/high) silica, is (intrusive/extrusive), and is (mafic/felsic) | 8. In tropical areas (chemical/mechanical) weathering is dominant, but in arctic conditions (chemical/mechanical) weathering is most common. |
| 9. Conglomerate is a (clastic/chemical/biogenic) sedimentary rock. | 10. Foliation in metamorphic rocks is caused by. . . |
| 11. The "Cambrian explosion" is partly due to the evolution of ____________________. | 12. Why is the oldest ocean crust only about 200 million years old? |
| 13. The Devonian period is known as the Age of ____________________. | 14. The oldest land plants are from the (Cambrian/Silurian/Carboniferous/Triassic). |
| 15. What is a nautiloid? | 16. Even though life has been around for billions of years, why aren't fossils from before the Cambrian common? |
| 17. The extinction at the end of the Cretaceous was most likely caused by. . .. | 18. What natural resources are linked to the formation of the Michigan basin? |
| 19. How did the closing of the Isthmus of Panama affect oceanic circulation? | 20. The Pleistocene is known for widespread (glaciation/deserts) and appearance of (*Homo sapiens*/the earliest horse). |
| 21. What are the two categories of seismic waves? | 22. When a continental plate and oceanic plate converge, which one will generally subduct and why? |
| 23. When two continents collide, will one of them get subducted? Why or why not? | 24. Why does eruption of basalt normally form shield volcanoes rather than the steep-sided stratovolcanoes? |
| 25. Is lava from a volcanic eruption the main cause of deaths? | |
| **Sample Test "A" Critical-Thinking Questions** | **Sample Test "B" Critical-Thinking Questions** |
| A. Are human activities contributing to a reduction in biodiversity on Earth? Discuss evidence that supports your position. | B. If humans were to disappear from the planet, what might happen? |
| C. What evidence of humans might be preserved as part of the geologic record? | |
| **Likert-Scale Questions** | |
| 1. It is important that my students understand earth science so that they can make informed decisions. | |
| 2. I feel confident teaching earth science. | |
| 3. I currently include topics from earth science in my classes. | |
| 4. If I have a question regarding earth science, I feel confident that I know where/how to find the answer. | |
| 5. I feel that I understand the basics about the evolution of our planet (physically and biologically). | |
| 6. I am comfortable with the geologic time scale. | |
| 7. On a scale of 1 to 5, how would you rank the effectiveness of distance education courses versus traditional courses? (i.e., Distance learning is ___ compared to traditional courses). | |
| 8. I encourage students to use the internet as a source of information. | |
| 9. I am confident I can help my students judge the quality of information found online. | |
| 10. I try to foster discussion among students about topics pertinent to class. | |
| 11. I typically have students manipulate real data in my courses. (Less than once a year/semester; several times a year/semester; less than once a week, but more than once a month; more than once a week) | |
| 12. In a typical class period, I spend the following amount of time lecturing (versus in-class discussion, or activities). (Less than 50% of the period; 50% of the period; 75% of the period; 100% of the period) | |
| 13. I have students prepare and debate a particular side of an argument in class (for example, have half the class argue that global warming is solely caused by humans, and have the other half argue that it is all natural cycles) with the following frequency: less than once a year/semester; several times a year/semester; less than once a week, but more than once a month; more than once a week. | |

into the curriculum. This comment was addressed in future offerings of the course by providing additional assistance to incoming teacher-students who were unfamiliar with distance-learning and other technology.

In addition, the master teacher helped the university faculty members who were overseeing the program to understand the impact of some changes that had been made in the state's expectations for students after the curriculum

**TABLE IV: Attitudinal questions for the pre- and postcourse tests.**

| Precourse Questions | Postcourse Questions |
|---|---|
| 1. Why did you register for this class? | 1. How do you think this course benefited you in your career? |
| 2. What courses do you currently teach? | 2. Are you interested in teaching an Earth systems course in the future? Will you be teaching one? |
| 3. How much background do you have with the earth sciences? | |
| 4. What are you most interested in learning about during this class? | 3. What was the most interesting part of this course? |
| 5. How do you feel about distance learning? | 4. How do you feel about distance learning? |

was first designed. The HSCEs were approved by the state between the time that the MS program was first developed and the time that the first course was offered. The master teacher helped the project team to understand the new HSCEs and identify areas in which the curriculum would need to be revised to address the HSCEs rather than their precursors.

In total, five (out of nine possible) teacher-students completed the precourse test, and all nine completed the postcourse test during the initial offering of the first online course (ESS I). Completion of the test was optional as it was used to evaluate the program rather than the teacher-students' performance. The mean score (Fig. 1a) on the precourse content-area exam was 66.4 (out of 100 possible, $n = 5$); the mean postcourse score was 84.6 ($n = 9$); the average overall gain score for participants that completed both the pre- and postcourse tests was 18.2 points (Fig. 1b, $n = 5$), with a range in overall gain scores of 7 to 25. The pre- and postcourse test scores for paired tests (pre- and postcourse tests both taken by a single individual, $n = 5$) were used to test the null hypothesis that the mean of the precourse scores was greater than or equal to the mean of the postcourse scores. A one-tailed paired samples $t$-test indicated that the observed gains were statistically significant ($p = 0.004$). The results of this study are not widely generalizable, however, due to the small sample size ($n = 5$), but they suggest that the online course helped participating teachers learn geoscience content. These initial results are important because they suggest that online instruction may be a viable way to help increase teachers' content-area knowledge. Additional data will be required to conclusively test the course's impact.

The average number of words (all types of words) used to answer the critical-thinking questions was 58.2 prior to the course ($n = 5$) and 93.3 after the course ($n = 9$). The average score on these questions was 1.5 for both the precourse ($n = 5$) and postcourse ($n = 9$) tests (out of a maximum possible value of 2.0 points per question). Respondents that completed both the pre- and postcourse tests ($n = 5$) showed an average increase in the number of words used to answer the questions of 105.4. Based on these results, it appears that the online courses had a positive impact on participants' willingness to produce an extensive written response to an open-ended problem. The results indicate that the quality of the answers did not increase as a result of taking the course, however. Scores were determined based on participants' use of data and logic in the answer, but many of the responses (both pre- and postcourse) were based primarily on individuals' personal opinions rather than logical arguments supported by facts.

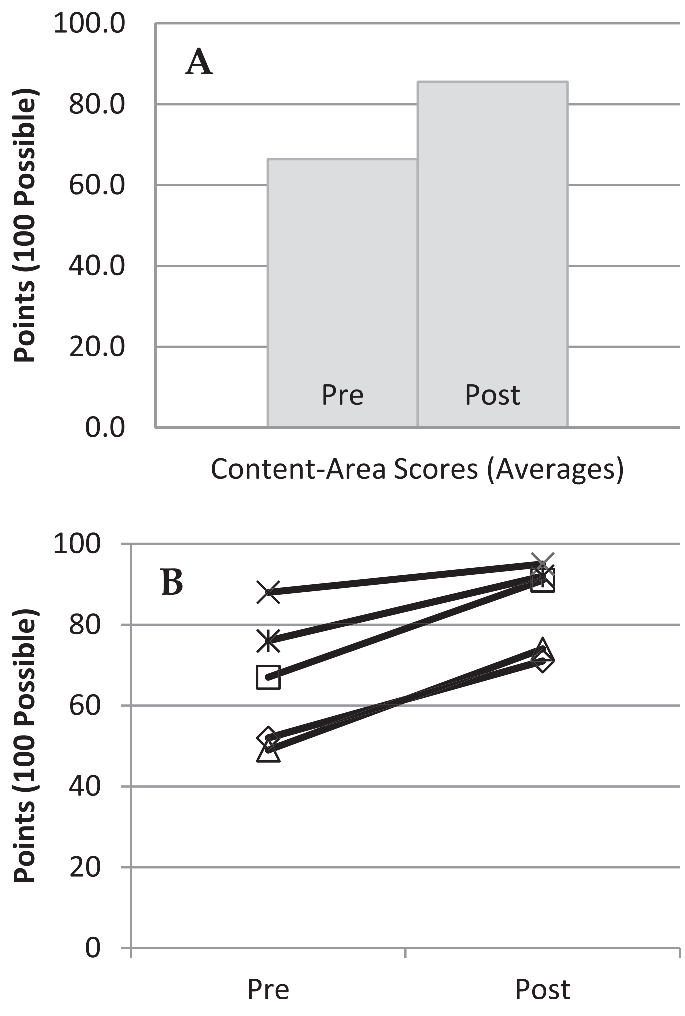


**FIGURE 1: Comparison of pre- and postcourse scores on a content-area exam. (a) Mean pre- ($n = 5$) and postcourse ($n = 9$) content-area scores for all teachers who took the tests. Taking the test was optional, and only five teachers took the precourse exam. (b) Pre- versus postcourse scores for teachers who took both the pre- and postcourse exams. Average gain was 18.2 points, and all teachers showed an increase in score on the postcourse exam. A ceiling effect is apparent for teachers who received relatively high scores on the precourse exam.**

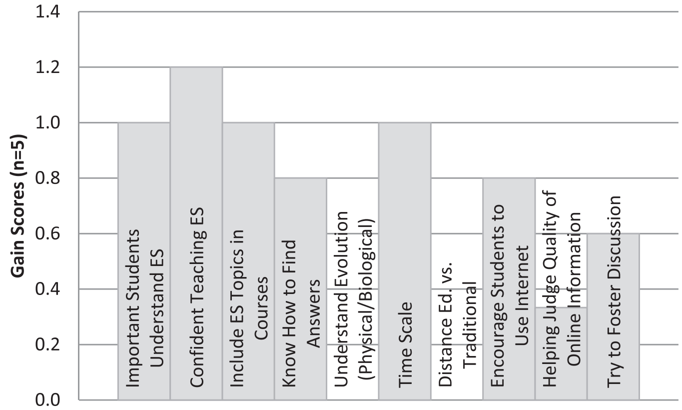


**FIGURE 2: Mean gain (post-pre) scores for the five teacher-students that completed both the pre- and postcourse surveys that asked for information regarding their classroom practice and attitudes.**

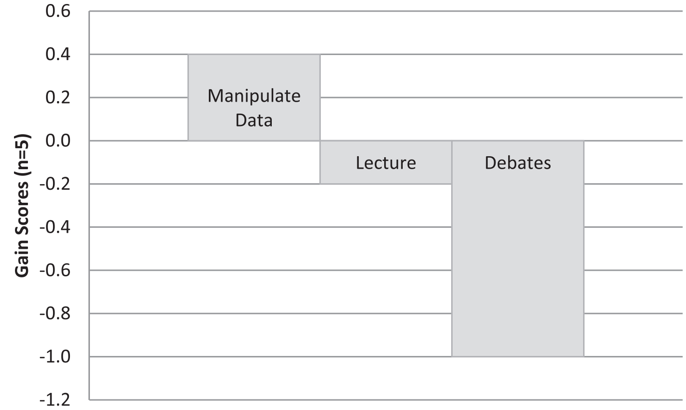


**FIGURE 3: Mean gain (post-pre) scores for the five teacher-students that completed both the pre- and postcourse surveys that asked for information regarding the teachers' use of data, lectures, and student debates as instructional methods in their classrooms.**

Responses to the Likert-scale and attitudinal questions indicate that participants who took both the pre- and postcourse tests ($n = 5$) increased their sense that it is important for students to understand earth science, their confidence in teaching earth science, their use of earth science topics in their courses, their knowledge of how to find answers to earth science questions on their own, their comfort with the geologic time scale, their encouragement of students to use the internet as a source of information, their ability to help students judge the quality of information found online, and their ability to foster discussion among their students (Fig. 2). There was no change in their reported understanding of physical and biological evolution or in the perceived effectiveness of distance education as compared to traditional education.

Participants who completed both the pre- and post-course tests ($n = 5$) indicated that they were more likely to have their students manipulate real data and less likely to lecture after taking the course (Fig. 3). They were less likely to have their students prepare for and take part in debates after the course than before. The practice teachers had in using real data during the online course probably contributed to their increased use of data in their own courses. The decrease in time spent lecturing is a positive outcome as it indicates that the students of these teachers would spend more time doing things rather than listening to lectures after the teachers took the online courses. The decrease in the teachers' use of classroom debates is inconsistent with the other results shown in Fig. 2. This is not a positive outcome unless time spent debating was replaced by another activity that required students to engage in critical thinking.

Participants' constructed responses to the attitudinal questions (Table V) regarding their perceptions of the course and its effects were categorized to facilitate interpretation. The majority of the responses indicated that the course met expectations, in that participants were exposed to and learned content that was directly related to what earth/space science teachers are expected to know and be able to teach. The fact that the course was explicitly tied to the geology of Michigan was viewed positively. Most participants felt that distance learning is not a replacement for traditional instruction, and many indicated that they missed having the opportunity to interact face-to-face with other teacher-students and the course instructor. The most positive benefit of distance learning was the fact that it was convenient; this was particularly true for single parents. Because the MS program includes distance learning, on-campus, and field-based components, the negative aspects of distance learning are presumed to be balanced by the intensive contact participants experience in the courses held on campus and in the field.

## Evaluation of the Master's Program Overall

Three years after it was first offered, the master teacher reviewed all materials for the second online course and provided an overall assessment of both online courses (ESS I and ESS II). By that time, each course had been taught three times and had been refined in response to the master teacher's earlier formative assessment as well as comments received from teacher-students who took the course. Interviews were also conducted with the seven teacher-students who made up the pilot cohort after they completed all or nearly all of the courses in the MS program. These interviews collected information about participants' overall perception of the MS program. A semistructured protocol was used (Table VI) for the interviews. The final component of the evaluation of the program was conducted by the state of Michigan when it considered the program as a path to subject-area endorsement in earth science for teachers who already possess full certification in another field.

Prior to considering any curriculum as a path to subject-area endorsement, the state of Michigan requires programs to submit documentation that they are aligned with standards and are likely to serve their intended purpose. This documentation includes complete syllabi for all required courses along with vitae for all instructional personnel; all documentation is available online (Michigan Tech Division of Teacher Education, 2008).

## Results of Evaluation of the Master's Program Overall

Key findings from the master teacher's evaluation of the online courses include the following.

**TABLE V: Summary of responses to pre- and postcourse attitudinal questions (*n* = 5).**

| Precourse | | Postcourse | |
|---|---|---|---|
| Question | Responses | Question | Responses |
| Reason joined program? | Certification = 1;<br>MS degree = 3;<br>Improved qualifications = 1 | Primary benefit of program? | Certification = 2;<br>Learning = 2;<br>Needed for job =1 |
| Courses taught during current year? | Earth science = 3;<br>Physics/Chemistry = 2 | Interested in teaching earth science in future? | Yes = 4;<br>Want to if possible = 1 |
| Earth science background? | 0–1 courses = 2;<br>>1 course = 2;<br>Teacher professional development only = 1 | | |
| Most interested in? | Rocks and minerals = 1;<br>Earth history = 1;<br>Multiple topics = 3 | Most interesting part of course? | Learning new information = 3;<br>Michigan geology = 2 |
| Like distance learning? | Like it = 2;<br>Neutral = 2;<br>Dislike it = 1 | Like distance learning? | Like it = 1;<br>Neutral =4 |

- Offering content-focused courses online and asynchronously is helpful to teachers juggling their personal and professional lives.
- The courses should be successful in strengthening teachers' content knowledge and instructional skills.
- The courses afford teacher-students numerous opportunities to collaborate with one another.
- Resources are appropriate to further teachers' understanding of the topics covered by the state of Michigan's High School Content Expectations (HSCEs).
- Content is challenging and appropriate for helping teachers to develop deeper understanding of the science underlying the HSCEs.
- Individual lessons are well-crafted to provide training for teachers who lack a background in earth/space science and will help such teachers effectively cover the topics with their students.

Interviews conducted with the seven teacher-students in the first cohort provided information about the program's value to its intended audience. Five of the teachers interviewed taught biology in the preceding year; only two taught earth/space science. Five of the teachers had taught earth/space science at some time in the past, however. Six teachers majored in biology or a life science in college. Five wanted to get their subject-area endorsement in earth/space science in the future; those that did not already had a general

**TABLE VI: Questions posed to participants in the master's program in a semistructured interview format.**

| Overall Topic | Additional Queries |
|---|---|
| Teaching experience | What subject(s) did you teach in the last year? What grade level(s) did you teach during the last year? When is earth science taught (at what grade level) in your school? Do you feel there is a need for a high-school level "refresher" course for students who take earth science in the eighth grade? Would it be appropriate for this course to be delivered online, face-to-face, or via a facilitated online delivery format? |
| Earth science preparation | If you didn't teach earth science in the last year, have you ever taught it? In what subjects do you have endorsement or certification? If you have earth science endorsement did you have it before the program, did you get it during the program, or are you planning to get it in the future? If you answered no to the three preceding options, why? What was your college major? What was your college minor? |
| Program-related | What led you to apply for program? Is getting an MS helpful in your district? Will it result in an increase in pay grade? Will it result in an increase in the respect you receive? Will it influence your career in other ways? What is your plan to complete your MS degree? What is your plan for your research project? Did the courses you took address the subject-area content needed? |
| Affect | Do you feel prepared to teach earth science content? Do you feel prepared to teach it at the middle-school level? At the high-school level? Do you feel confident that you can teach it well? Do you feel confident about finding out answers to questions you may have in the future? |
| Future, postproject | Are you likely to teach earth science in the future? Are you likely to use earth science examples in non–earth science courses? Are you likely to use real-world earth science examples in your courses? Are you likely to use inquiry-based instructional methods? Are you likely to take on leadership roles in your school or district in the future? Are you likely to participate in any professional networks that serve earth science teachers? |
| Summary | What was the best part of the program? What was the worst part? Do you have any recommendations for improvement? Do you have any questions? Do you have anything else to add? |
| Follow-up | Is it ok if someone contacts you in the future regarding the program? |

science (also known as DX in Michigan) endorsement that allows them to teach any science at the secondary level. Five of the teachers signed up for the MS program because they wanted to learn more about earth/space science. Two joined because courses were offered online during the academic year, making it possible for participants to continue teaching while working toward their MS. Three had participated in the National Science Foundation–funded Teachers' Earth Science Institute (TESI) in the past, and one had participated in a Michigan Tech summer program when they were in high school. All of the teachers reported that earning a MS results in a pay increase, but two were already at the MS pay grade. Four stated that they would be more respected by their colleagues or district administrators if they had a MS; five stated that their students would not care. Three of the teachers felt that participating in the program and earning a MS would help them reach their long-term career goals.

Three of the teachers taught in a middle school, and four taught in a high school during the preceding year. Five teachers reported that earth/space science is taught in eighth grade in their districts. Five stated that there was a need for some sort of high-school "refresher" course to help students who took earth/space science in the eighth grade prepare for the high-stakes high-school Michigan Merit Exam (MME). Four teachers thought that offering a refresher course as a facilitated online course would be best. A facilitated online course was defined as one that has all materials required for the course prepared in advance by content-area and pedagogy experts, made available online to teachers and students, and taught in the classroom by a teacher who ensures that students are active participants.

Six of the teachers were already thinking ahead to what they would work on for the research project required for the MS or had already completed their research at the time of the interview. One teacher was unsure of what needed to be done and wanted more advising but was unclear about who to contact for help. All reported that the courses they had taken during the program addressed content and pedagogy aligned with the HSCEs. All felt the program would be helpful in preparing teachers to teach earth/space science. All had extremely positive comments for the Geology of Utah's National Parks course, stating that it was "excellent," "awesome," "a remarkable experience," and "best thing I ever participated in besides TESI." Reviews of the Natural Hazards and Human Impacts course were mixed. Some recommendations for improvement included: provide more structure and focus less on the Houghton area and more on general implications.

The teachers felt the online courses (the ESS courses and the education courses) were very demanding, but useful. Most mentioned that they missed having face-to-face interactions when taking online courses. One teacher felt the lectures in the online ESS courses should be shortened. One suggested that the relevance of the course's materials to classroom teachers could be improved by having a teacher collaborate with the course instructor. Other suggestions for improvement included: provide clearer guidelines, that is, one document with all expectations, directions, and due dates; model inquiry in the teaching of the courses; and hold some "real-time" conferences.

Specific recommendations for improvement of the online education courses were also given: teach about inquiry while modeling inquiry; eliminate timed quizzes (software or hardware issues made it hard for some teachers to complete the quizzes within the time allowed); encourage teacher-students to take only one education course at a time; and do something to help those teacher-students who do not have perfect self-discipline to stay on track in the classes.

All of the teachers felt that they were prepared to teach earth/space science content well at either the middle- or high-school level. They all reported that they felt prepared to find answers to questions on their own; one reported that the MS program helped them to become better critics of what they read. All hoped that they would be given the opportunity to teach earth/space science in the future in their districts. All of the teachers also planned to use earth science examples in other courses that they teach, for example, using the carbonate compensation depth as an example in a chemistry course. All reported that they were using more inquiry-based instructional techniques after participating in the MS program than before, and five felt confident that they were doing a good job at implementing inquiry-based instruction. Two reported that they felt they needed to do more in this area.

All reported that they were already leaders in their districts and that they participated in teacher networks, for example, the Michigan Earth Science Teachers Association. The interviews revealed that, in general, the best parts of the program were: networking with other teachers and the university professors (4 responses), being engaged in field-based hands-on activities (4 responses), and completing the Geology of Utah's National Parks course (3 responses). Four teachers reported that the worst parts of the program were the education courses. Despite this negative comment, it must be noted that all of the teachers stated that the education courses were useful. Their challenging nature may have caused the teacher-participants to view these as the most demanding aspect of an overall positive experience.

Two specific summary comments for improvement of the MS program overall were: "Improve communication and collaboration among education and geology faculty," and "provide more and better advising to students in the program." All felt that the program provided a convenient schedule with the online and summer courses. Other summary statements included:

> *"This was a life-changing experience; now I read more about geology and reflect more on how I teach."*
>
> *"I learned a lot and would like to come back and work with new cohorts in the future."*

It is interesting to note that a colleague of one of the participating teachers also appears to have benefited from the program. This colleague (who was not a participant) wrote: " I am a colleague of .... I just want to let you know how much I appreciate their life journal. I teach the AP Biology classes here, and I will use this wonderful Powerpoint as a tool in my classes."

The life journal was one requirement for the completion of ESS I. It provided a summary of the major appearances and extinctions of life on Earth. The teacher referred to in this email did the journal as a Powerpoint presentation so that it could be easily shared with others.

The state of Michigan was first sent information about the new MS program, along with a request that this new program be officially recognized as a route to subject-area endorsement in earth science, on 21 December 2007. In February of 2009, the state declined the initial request and requested additional information about the program. During the spring and summer of 2009, the project team responded to the state's questions. The state reviewed the team's responses and approved the MS program as a path to subject-area endorsement on 4 January 2010. The MS program is now recognized as a path to secondary-level endorsement in earth/space science (Michigan Department of Education, 2010).

Of the seven teachers who participated in all components of the project, four have taken the Michigan Test for Teacher Certification (MTTC) in earth/space science; two passed on their first attempt. This represents a 50% pass rate for the first-time test takers. One participant does not intend to take the test. The other two participants intend to take the MTTC test in the near future.

The MS curriculum demonstrates one way in which extensive state requirements can be effectively addressed by a relatively small number of required courses. Having a modest number of required courses is beneficial to the teachers in the program as well as their students because it reduces time to degree, tuition expense, and allows for greater flexibility in the choice of electives. The program continues to be offered, and 20 students were enrolled in ESS I for fall semester 2011.

## DISCUSSION

It is clear that the MS program was effective in preparing a small group of out-of-field earth/space science teachers to pass a subject-area endorsement test and teach earth/space science. Although the field-based courses were most popular overall, the online courses were viewed as highly convenient, particularly by single parents. The results of the evaluation indicate that the online courses should incorporate more inquiry-based instructional practices and examples that could be used in the teachers' own classrooms.

Four members of the pilot cohort of seven teacher-students have taken Michigan's subject-area endorsement test in earth/space science, and two passed the test on their first attempt. This is a positive outcome, as the current statewide pass rate for first-time test takers in earth/space science is a mere 25%, and the cumulative pass rate is only 40%. It should be noted that pass rates in earth/space science are well below rates in other subjects, which range from 65% to 99% for first-time test takers. With such low pass rates in earth/space science, the state runs the risk of not having enough teachers certified in earth/space science to continue to offer the subject. Our MS program may be a successful model for preparing existing teachers to pass the state exam and teach earth/space science content. Since the program can be completed in two years, teachers who participate in it can rapidly update and broaden their skills. This is important at the current time because many Michigan districts are losing population and being forced to lay off teachers. As a result, it is becoming increasingly common for the few experienced earth/space science teachers who are currently in the workforce to be reassigned to teach one of the required "core" sciences (biology, chemistry, and physics). The MS program is a time- and cost-effective way to increase the size of the earth/space science workforce because it provides focused training in geoscience to teachers who are already certified to teach one or more of the other sciences. This additional training is particularly helpful to teachers who possess the general science (no longer offered) or integrated science endorsements, since these emphasize breadth rather than in-depth understanding of any particular discipline. Earth/space science is an ideal subject to engage these teachers because geoscientists commonly apply techniques, tools, and habits of mind that are drawn from many of the other science disciplines as well as mathematics.

Based on our informal discussions with teachers in the program, we feel that it is extremely important for the geoscience and education communities to work together to increase the size of the earth science teacher workforce through programs such as this. Skilled teachers who are active in their schools may be the most effective proponents of continued inclusion of earth/space science content in secondary curricula. Teachers who have the respect of their colleagues and supervisors are able to demonstrate to principals and school boards that earth science is relevant and can be used to provide context and hands-on learning opportunities in the other sciences and mathematics. Students who participate in good earth science courses are well prepared to meet the benchmark expectations in all sciences (Barstow et al., 2001).

## CONCLUSIONS

The results of this study provide strong evidence that a carefully designed curriculum, which includes online courses during the academic year and field-based courses during the summer months, can successfully prepare out-of-field teachers to teach earth/space science content. The fact that the program leads to a MS makes it attractive to teachers, who will receive pay increases and/or increased respect in their districts after completing a postgraduate degree. The approach described in this paper shows promise as a model for increasing the size of the earth/space science teacher workforce.

Some important lessons were learned during the project. First, close collaboration by geoscience and education faculty was required to develop the curriculum and get it approved by the state. The importance of this collaboration cannot be overemphasized. Second, taking the state's requirements for teacher preparation as well as the HSCEs into account at the very beginning of the curriculum design process ensured our eventual success in obtaining state approval of the program as a path to subject-area endorsement. Third, obtaining advice from a practicing master teacher helped to ensure that the curriculum would be valuable to teachers. Finally, and perhaps most importantly, we demonstrated that stand-alone courses in specific subjects are not necessary to meet requirements for teacher preparation. Carefully designed integrative courses can introduce content effectively while requiring fewer credit hours. This is an important result because both time-to-degree and the cost of paying for the credits required for a degree are of great concern to most practicing teachers.

### Acknowledgments

Development of the MS program was made possible by a grant from the Geoscience Education Program at the

National Science Foundation (GEO-0608039). Many people worked on this project, and we thank all of them for their efforts to get more qualified earth/space science teachers into classrooms. In particular, we thank Drs. Wayne Pennington and John Gierke, who ensured that the online courses were always available, Drs. Kedmon Hungwe, Bill Yarroch, Chris Wojick, and Bill Rose for serving as instructors or co-instructors for courses in the program, Dr. William Everham for assisting with the curriculum development effort and teaching the Geology of Utah's National Parks course during the project, and Dr. Thomas Drummer for help with quantitative data analysis. We thank Ms. Carol Engelmann and Mr. Cris DeWolf for assisting with project evaluation. Finally, we thank Ms. Alex Guth for her instructional efforts in the online courses.

## REFERENCES CITED

Barstow, D., Geary, E., Yazijian, H., and Schafer, S. 2001. Revolution in earth and space science education: Blueprint for change: Report from the national conference. June 21–24, 2001, Snowmass, Colorado. Cambridge, MA: TERC. p. 100.

Blank, R.K., and Toye, C. 2007. 50-State analysis of the preparation of teachers and the conditions for teaching: Results from the NCES schools and staffing survey. Washington, DC: Council of Chief State School Officers. p. 22.

Coble, C., and Allen, M. 2007. Keeping America competitive: Five strategies to improve mathematics and science education. Denver, CO: Education Commission of the States. p. 8.

Geary, E., Hoffman, M., Stevermer, A., and Barstow, D. 2005. Progress and setbacks in K-12 earth and space science education during the past decade. *Eos Transactions, American Geophysical Union*, 86(52), Fall Meeting Supplement, Abstract U11C-01 p. 8.

Glenn Commission. 2000. Before it's too late: A report to the nation from the National Commission on Mathematics and Science Teaching for the 21st Century. Washington, DC: U.S. Department of Education. p. 43.

Ingersoll, R.M., and Perda, D. 2009. The mathematics and science teacher shortage: Fact and myth. The Consortium for Policy Research in Education CPRE Research Report #RR-62, p. 45.

Kind, V. 2009. A conflict in your head: An exploration of trainee science teachers' subject matter knowledge development and its impact on teacher self-confidence. *International Journal of Science Education*, 31:1529–1562.

Massa, N.M. 2008. Problem-based learning (PBL): A real-world antidote to the standards and testing regime. *New England Journal of Higher Education*, 22:19–20.

Means, B., Toyama, Y., Murphy, R., Bakia, M., and Jones, K. 2009. Evaluation of evidence-based practices in online learning: A meta-analysis and review of online learning studies. Washington, DC: U.S. Department of Education Office of Planning, Evaluation, and Policy Development, Policy and Program Studies Service. p. 90.

Michigan Department of Education. 2010. Approved teacher education programs. Available at https://mdoe.state.mi.us/proprep/Collegeinfo.asp?College_id=20 (accessed 3 March, 2012).

Michigan Department of Education. 2011. Facts on educator certification. Lansing, MI: Michigan Department of Education, Office of Professional Preparations Services. p. 18.

Michigan Technical University. Division of Teacher Education. 2007. Master of science in applied science education student handbook. Houghton, MI: Michigan Technological University. p. 24.

Michigan Technical University. Division of Teacher Education. 2008. State of Michigan periodic review / program evaluation. Available at http://www.ed.mtu.edu/PeriodicReview/EarthSpace/index.html (accessed 3 March 2012).

Mississippi State University. 2010. Teachers in geosciences program. Available at http://www.distance.msstate.edu/geosciences/TIG/index.html (accessed 3 March 2012).

National Center for Education Statistics. 2009. Digest of education statistics, chapter 2, elementary and secondary education. Available at http://nces.ed.gov/programs/digest/d09/tables_2.asp (accessed 2 March 2012).

National Science Board. 2006. Science and engineering indicators, chapter 1, elementary and secondary education, mathematics and science teachers. Available at http://www.nsf.gov/statistics/seind06/c1/c1s3.htm (accessed 3 March 2012).

Pennsylvania State University. 2011. Earth sciences (Master of Education). Available at http://www.worldcampus.psu.edu/degrees-and-certificates/earth-sciences-masters/overview (accessed 5 September 2011).

Pepper, C. 2009. Problem based learning in science. *Issues in Educational Research*, 19:128–141.

Rutherford, S. 2008. Earth science education matters! A master's degree program for in-service teachers. *Journal of Geoscience Education*, 56:378–382.

Seastrom, M.M., Gruber, K.J., Henke, R., McGrath, D.J., and Cohen, B.A. 2002 revised 2004. Qualifications of the public school teacher workforce: Prevalence of out-of-field teaching 1987–88 to 1999–2000. Washington, DC: Department of Education Institute of Education Sciences. p. 104.

Shulman, L. 1986. Those who understand: Knowledge growth in teaching. *Educational Researcher*, 15:4–14.

Singer, S.R., Hilton, M.L., and Schweingruber, H.A., eds. 2005. America's lab report: Investigations in high school science. Washington, DC: National Academies Press. p. 254.

Wiggins, G., and McTighe, J. 2005. Understanding by design, 2nd edition. Alexandria, VA: Association for Supervision and Curriculum Development (ASCD). p. 370.