The Ongoing Educational Anomaly of Earth Science Placement

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ABSTRACT

The geosciences have traditionally been viewed with less "academic prestige" than other science curricula. Among the results of this perception are depressed K-16 enrollments, Earth Science assignments to lower-performing students, and relegation of these classes to sometimes under-qualified educators, all of which serve to confirm the widely-held misconceptions. An Earth Systems course developed at San José State University demonstrates the difficulty of a standard high school Earth science curriculum, while recognizing the deficiencies in pre-college Earth science education. Restructuring pre-college science curricula so that Earth Science is placed as a capstone course would greatly improve student understanding of the geosciences, while development of Earth systems courses that infuse real-world and hands-on learning at the college level is critical to bridging the information gap for those with no prior exposure to the Earth sciences. Well-crafted workshops for pre-service and inservice teachers of Earth Science can help to reverse the trends and unfortunate "status" in geoscience education.

Keywords: Earth Systems Science; Education – Precollege; Education - Teacher education; Education - Undergraduate

INTRODUCTION

The reputation of the geosciences as a "Rocks for Jocks" curriculum has long permeated K-12 districts and college campuses. In undergraduate programs, Geology has sometimes been viewed as a more accessible science-requirement-satisfying option for non-science majors. On the secondary level, earth science has been a course traditionally offered to non-college-bound populations, as an alternative to the more "academic" track including Biology, Chemistry, and Physics.

Despite the National Science Education Standards' call for Earth Science to be taught at each K-12 grade level (NRC, 1996), Earth Science is increasingly relegated to earlier grades, thus allowing college-bound high school students to take at least one Advanced Placement class in their senior year in lieu of any earth science at all. In California, for example, Earth Science is last taught as a comprehensive course in the sixth grade. While elements of the geosciences are incorporated into later Integrated Science curricula, it is not atypical for California's youngsters to obtain their only exposure to the breadth of earth science in their first year of middle school: and this is in a state where earthquake preparedness is a required topic throughout one's public education. In New York State, where the Board of Regents has maintained statewide standards by requiring exit exams in all high school-level curricula, Earth Science has been relegated increasingly to middle schools.

Earth Science is neither a topic for slow learners nor for young learners. This conclusion was never as apparent to these authors as during the course of an unintentional, unplanned "experiment," in which what is effectively a high school syllabus in Earth Science was taught to groups of upper division undergraduates at San José State University.

THE EARTH SYSTEMS APPROACH

Geology 103, Earth Systems Science, is a course that was developed by Prof. Ellen Metzger in 2000 at the request of the Director of the Program in Science Education. It was recommended that SJSU's pre-credential and inservice teachers would greatly benefit by having a comprehensive course in which earth science would be explored in depth. While the curriculum was initially designed to satisfy the needs of secondary science teachers, Geology 103 was recently mandated for all students enrolled in the university's multiple-subject credential program, since it satisfies content and pedagogy requirements as deemed necessary by the California Commission on Teacher Credentialing (CCTC) and the National Council for Accreditation of Teacher Education (NCATE). As such, the curriculum also awards General Education credit (thus fulfilling part of university-wide graduation requirements) to keep the prospective teachers' bachelor's degrees within an acceptable credit range.

The course was piloted in spring 2001, and has been taught since then by either Ellen Metzger or Paula Messina, both joint appointees of SJSU's Geology Department and Program in Science Education. Dr. Metzger brings to this course over a decade of experience as co-director of the Bay Area Earth Science Institute (BAESI), an SJSU-based program funded by the National Science Foundation, SJSU, Chevron Texaco Corporation, and other community partners, which has served over 1,100 Bay Area teachers in summer and Saturday workshops. Many of the BAESI teachers indicate that their motivation for participation correlates to the increasing expectation for them to teach Earth Science with little or no prior coursework in the subject. The opportunity to work with pre-college teachers has influenced Metzger's own teaching and she now incorporates more active learning strategies in her own classes, including Geology 103. Prior to her appointment at SJSU, Dr. Messina taught high school Earth Science to middle- and high-school students in New York City. For most of her twenty-year K-12 teaching career Dr. Messina taught the New York State Regents syllabus in Earth Science, which was offered in her school predominantly to "gifted" freshmen and to juniors who were deemed "under-qualified" to succeed in Chemistry.

A TALE OF TWO CREDENTIALS

As part of the science teacher credentialing process in California, one must demonstrate subject matter competency in the geosciences, which is typically accomplished by successful completion of courses in Astronomy, Geology, Meteorology, and Oceanography. Given the time-intensive professional demands of new teachers, it was clear to many of SJSU's Science Education faculty that requiring four semester-length courses was unrealistic, and that the salient content and process skills could be covered in a single comprehensive earth systems curriculum.

In contrast, New York State-licensed Earth Science teachers may obtain their teaching credentials by proving subject matter competency in a single discipline, geology for example, despite the fact that the Regents-endorsed syllabus incorporates atmospheric, oceanographic, and space sciences.

A more problematic corollary to the "demotion" of Earth Science to earlier grades is the less-comprehensive teacher science training requirements for those seeking multiple subject (elementary school) credentials. It is possible that someone teaching Earth Science to sixth-graders in California may never have taken a geoscience class at all. Hence, as his or her terminal earth science experience, a student may have a teacher who has little more content area and process skills training than any number of liberal arts college graduates. In New York State, one may obtain a high school teaching license specific to a discipline (i.e., Earth Science, Physics, Chemistry, etc.), or a middle school "General Science" license. When the high school-level Regents Earth Science curriculum is offered to eighth graders, as is done increasingly, there is no guarantee that the teacher of that course has successfully completed a single college-level course in any of the geosciences.

There appear to be as many science teacher credentialing standards as there are national, statewide, and district K-12 science content standards nationwide, and in no discipline is it more apparent than in the geosciences. The old adage that "anyone can teach Earth Science" (Nuhfer, 1990) is still routinely applied in schools around the country. The Council of Chief State School Officers (2001) reports that there are severe shortages of certified teachers in Earth Science, with only 82% of teachers across the nation being certified; certification rates in physics, chemistry, and biology are consistently higher. What a disservice we are doing to our youngsters by first portraying Earth Science as a "lesser" curriculum, not to be compared to the traditional college-bound science courses, and then allowing less-rigorously-prepared teachers to head those classes.

Given the current climate, it is not surprising that high school students opt for classes that carry more perceived academic clout (and in which the teachers may be better prepared), and that prospective science teachers consider careers instructing Chemistry or Physics—where they know they will encounter more motivated students. Thus is the self-fulfilling prophecy of the Earth Sciences in K-16 education.

A SINGLE COURSE TO SATISFY A DIVERSE AUDIENCE

In addition to the obvious streamlining benefits to K-12 teachers, Geology 103 was designed to incorporate effective pedagogy as an integral part of the curriculum. It is not a traditional instructor-centered lecture/lab class, but one in which students practice the process of science through activities, discussion, and guided inquiry. The advantage to K-12 teachers of this method of instruction to K-12 teachers is apparent, since they are offered a hands-on approach to complex concepts which they can then in turn adopt for their own classrooms. Class notes and activities have been made available online through the following Web sites (http://geosun.sjsu.edu/paula/103 and http://geosun.sjsu.edu/~metzger/103.htm) so that teachers may freely print and use Geology 103 activities and slide sets with the kids they teach.

Among the benefits to non-teachers enrolled in the class is the opportunity to learn by doing, a method that has been all but overlooked in traditional college lecture courses. Non-teachers may enroll in this class to satisfy one of many General Education requirements for graduation, but the class is open only to juniors and seniors. By scheduling the course in the evening (to allow inservice teachers the opportunity to take it during the school year), Geology 103 has typically attracted non-traditional upper level undergraduates with majors as diverse as Marketing, Psychology, and Music in addition to those pursuing master's degrees in Education and Natural Science. Most people who have taken Geology 103 are working adults attending college part-time; so far, students have ranged in age from their early 20s to their late 70s, with a majority in their late 20s to mid 30s.

While in its planning stages the success of Geology 103 seemed to be a challenge, given its diverse audience. As an approved General Education course, over-arching goals included "the cultivation of knowledge of the scientific study of the physical universe and its life forms; an understanding and appreciation of the interrelationship of science and human beings to each other" (SJSU, 1998). As a course that would satisfy pedagogical- and subject area-competency requirements for both multiple- and single-subject credential teachers, it also needed to incorporate the scope and depth mandated by rigorous California state education standards (California Department of Education, 2002). Hence, goals of the curriculum are numerous, and often dictated by external committees or agencies.

Assessment of student work includes exams, papers (there is a significant writing requirement for all SJSU GE courses), oral presentations, concept maps, and "WebQuests." A WebQuest is a type of guided Internet-based exercise developed by Bernie Dodge and Tom Marsh at San Diego State University (Dodge, 2003). WebQuests consist of a task that is interesting and doable, learning advice, and links to Web sites selected to facilitate the task. Geology 103 WebQuests focus on controversial topics such as global warming and what killed the dinosaurs. Informal assessments permeate the course, especially during and after its student-centered hands-on components.

Despite the multiple and coincident requirements, Geology 103 has proven to be a popular course among teachers and non-teachers alike. The online component is widely appreciated by its enrollees who have professional and personal commitments beyond those of the traditional undergraduate, and its integrated hands-on design makes its content accessible to students of varied backgrounds and interests. Furthermore, the Earth Systems approach promotes the multidisciplinary nature of science, wherein an understanding of the whole requires an awareness of many components and how they interact, concepts sometimes overlooked within a narrower discipline-specific view of science. Other themes, which include scale, cycles, energy, and human interactions with Earth spheres, encourage students to find patterns, analyze scenarios, and construct solutions to pertinent everyday problems.

QUESTIONS OF SUITABILITY

In the fall 2001 semester, Paula Messina taught Geology 103 for the first time; after consulting with the curriculum developer and initial course instructor, Ellen Metzger, she adapted the course to suit the needs of its students (by reviewing previous course evaluations), while teaching to her strengths (which encompassed traditional geology and a broader physical geography/ Earth science background). The textbook selected, *Earth Science*, 10e. by Tarbuck and Lutgens (Prentice Hall, 2002), delves into the solid Earth, atmosphere, hydrosphere, biosphere, solar system and beyond, with careful regard to their influences on each other. Messina immediately recognized that the scope of the selected text was very similar to the Regents Earth Science course she had taught in New York State.

Regents Earth Science was developed for high school students, and as mentioned previously, it is increasingly being offered to students in earlier grades. Despite the fact that Geology 103 is an introductory course (which carries General Education credit), it seemed impracticable to present the material in a comparable manner and at a similar level to adult learners. Would the students sense condescension if this were the case?

Messina pondered these dilemmas before the start of the semester, reflecting on experiences while leading summer institutes for BASEE (Bay Area Schools for Excellence in Education), an NSF/Hewlett Packard-sponsored program designed to enhance elementary teachers' science content knowledge. It was through BASEE that Messina recognized the K-6 teachers' needs for basic understanding of scientific concepts. During two weeks of BASEE workshops in 1999, Messina developed and taught Earth Science content through a variety of hands-on methods to adult learners. While the teachers enrolled in the workshops had a true motivation to learn, higher educational achievements, and much more life experience than high school freshmen, their prior knowledge of the geosciences was somewhat similar. The course was taught at a level comparable to the NYS Regents Earth Science syllabus; many of the activities were taken directly from the labs developed for high school students. To some, this was the first such instruction they had ever received.

The BASEE teachers remarked that they were grateful to finally have had the opportunity to learn geoscience concepts (which they in turn were required to teach their own sixth-graders) in a way that they could understand. They were honored to have been treated as adult learners, although admittedly learning content typically made available to much younger populations that they had never had the opportunity to explore previously.

Could it be that, when planning for Geology 103, one should assume a similar lack of prior knowledge? Would college students, particularly non-traditional upper-classmen, benefit from exposure to a syllabus that was at the same time being taught to middle- and high-school students 3000 miles away? Or would it be viewed as "dumbing down" the curriculum?

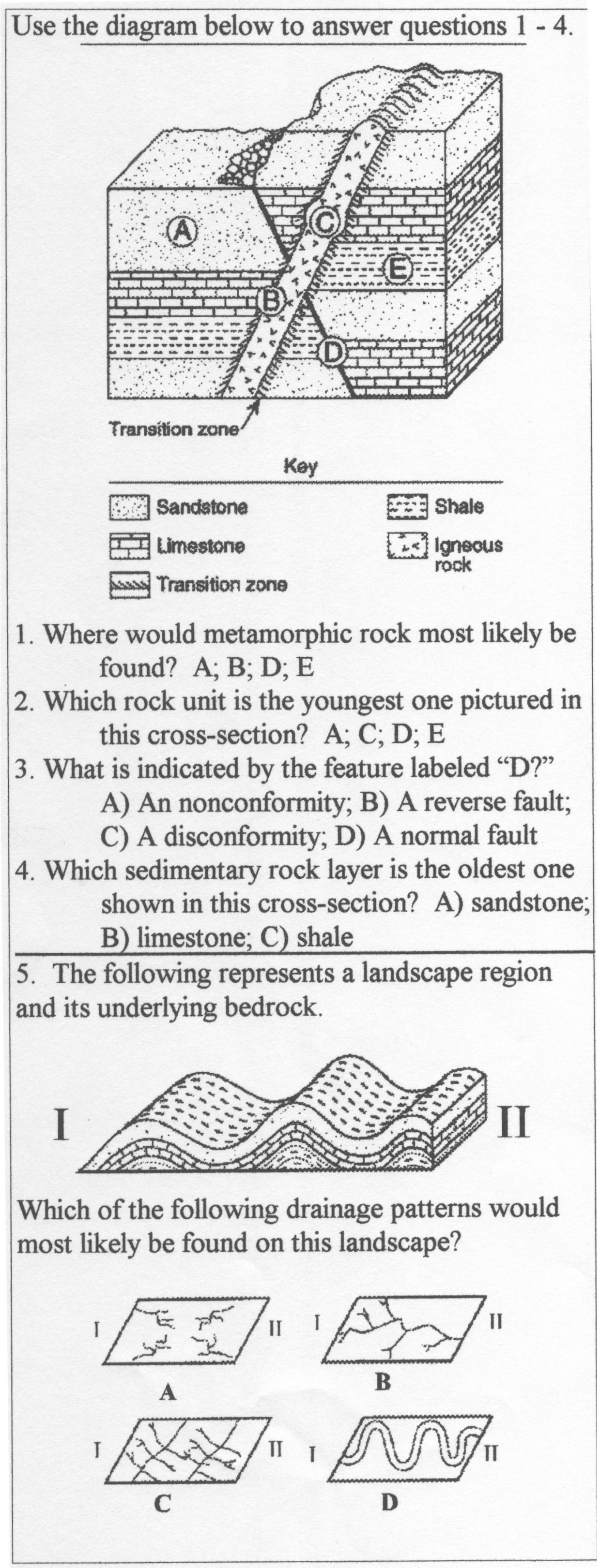
THE "EXPERIMENT"

In fall 2001, the content and teaching methods of Geology 103 closely paralleled those of the Regents Earth Science syllabus in which Messina had ample experience. Each class began with a "hook," a discrepant event or pertinent demonstration of an unexpected phenomenon, a hands-on activity (conducted by an individual or groups of students), and a series of instructor-led discussions which were illustrated with PowerPoint slide sets and animations. Activities were adapted from labs Messina had conducted with her ninth-graders; language and procedures were modified somewhat to reflect the age and experience of adult learners. Tests were constructed with selected questions from prior New York State Regents Earth Science exams, sometimes verbatim.

Long before the publication of the AAAS's *Science for All Americans* (Rutherford and Ahlgren, 1990) New York State had an ongoing history of implementing subject matter standards in the sciences, as well as for all other secondary school subjects. Exit exams, administered by the New York State Board of Regents, are developed and administered annually as the terminal assessment instruments for standardized state-approved curricula. Earth Science is a Regents-level curriculum in New York State, an elegant amalgam of earth and space sciences. Two contributors to this paper - Messina and Paul Speranza, a recently-retired New York State Earth Science teacher and co-author - have collectively taught over 5000 students in total, representing over 50 years of Earth Science teaching.

The Regents syllabus in Earth Science was first developed in 1970, but has been revised several times since then to reflect the dynamic nature of the geosciences. As with all NYS Regents science syllabi, the course requires at least 30 hours of laboratory work to be conducted by each student; those failing to meet this requirement are barred from taking the uniform exit exam. Earth Science was the first curriculum to include a "practical" component to the cumulative statewide exam, which tested students' laboratory skills (i.e., measuring, classifying, etc.) and reasoning abilities (i.e., extrapolating and interpolating student-collected data). This practical component had been long-touted as a "model instrument" after which the exit exams of other curricula were to be re-designed. It is still the only Regents science with a performance portion of the exit exam.

The curriculum itself spans geology, oceanography, meteorology, and astronomy. As a basis for understanding many of the Earth systems explored, metric measurement, density, gravitation, energy conversions, transfer methods, and specific and latent heat (and their influence on adiabatic lapse rates, etc.), are also an integral part of the course.



Figures 1A, 1B, Excerpts from a Geology 103 exam, showing questions adapted from the New York State Earth Science Regents exams. Despite their multiple- choice format, questions are devised in such a way to test reasoning skills, and not rote memory.

GEOLOGY 103 EXAMS

In the college class equivalent, study guides were distributed before each exam and made available through the course Web site. Each study guide contained an outline of directed questions reflecting the scope of required content. Students had voted in favor of multiple-choice format questions for their first and second exams, and so each unit test contained items taken directly from New York State Regents exams (databases and old exams are available in the public domain from several regional school districts and New York State's Earth Science Regents archive <http://www.emsc.nysed.gov/ciai/testing/scire/regentearth.html>). In each case, the study guide was used as the outline from which questions were selected.

As per the design of Regents-level multiple choice exams, selected questions required higher-order reasoning and an application of knowledge and process skills (Figures 1A and 1B). Rarely, if ever, does the NYS Regents include questions that may be answered by simple memorization of trivial facts.

Before Geology 103's first exam was administered, it was unclear whether the level of difficulty of the exam was appropriate for upper-division undergraduates; afterwards, it was a revelation to assess the results. The test, which was composed of 50 multiple choice questions (four choices per question), was viewed as being "very difficult" when students were queried. One student spoke to Messina after class, and explained that "this is an introductory class," and that the exam was unnecessarily challenging. The comments were as shocking to the instructor as were the summative statistics: mean score (66%); range (38% – 94%). The second exam yielded similar results: mean score (74%); range (43% – 94%).

Before the third and final unit test (N.B.: unlike the Regents exam, the final for Geology 103 is not cumulative), many students requested greater variety in the types of questions included; some claimed that they historically blundered on multiple choice/short answer exams, and they preferred a short essay format. To satisfy a majority of students, the third exam was designed to include the student's choice of either 40 multiple choice questions (100%), or 30 multiple choice questions (60%) and 2 short essays (40%). All students were given the opportunity to select the 40 (or 30) short-answer questions of their choice (without restrictions, out of a total of 50); if opting to answer essays, students could choose two of a possible three.

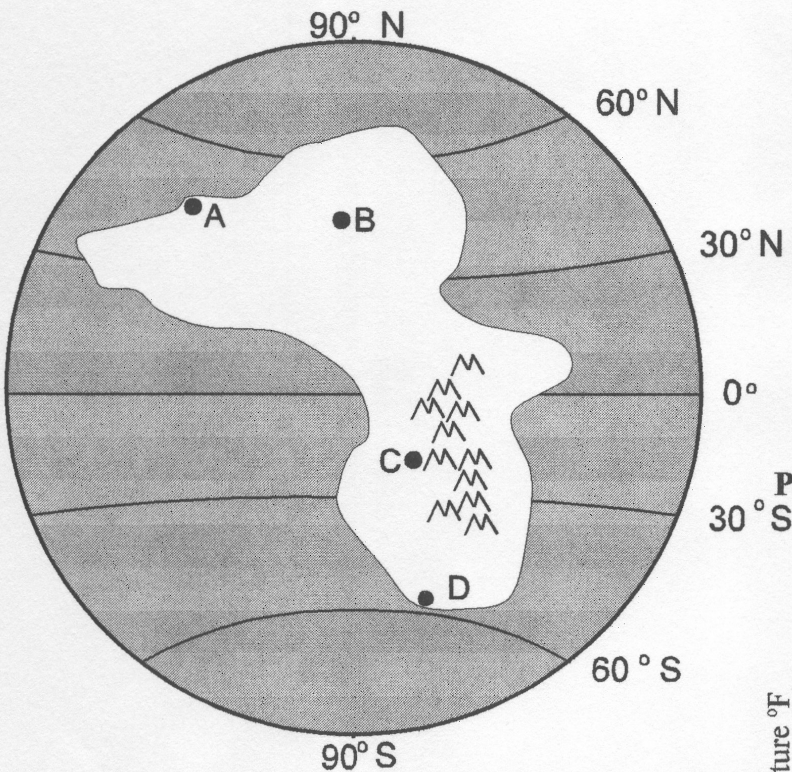
Of 20 students who took this exam, only 6 chose the multiple choice/short essay format. Results for both formats were comparable: mean score (64% vs. 72%, for the multiple choice and mixed-format tests, respectively); range (41% - 97% vs. 33% - 95% for the multiple choice and mixed-format tests, respectively).

ASSESSMENT

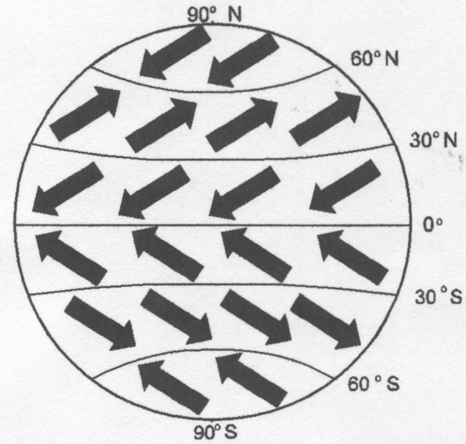
What could these surprising results imply? Perhaps the quality of instruction was deficient, but perhaps the curriculum is far more difficult than it has been traditionally viewed.

A comprehensive course evaluation was devised and distributed to students along with the "final" exam. In it, open-ended questions asked for students' opinions on the scope, sequence, and presentation of the material

Questions 6-8 refer to the map below, left showing four locations, labeled A, B, C, and D, on an imaginary continent called "Messinaland." Planetary wind belts are shown below, right. Answer questions 6-8 based on these diagrams.

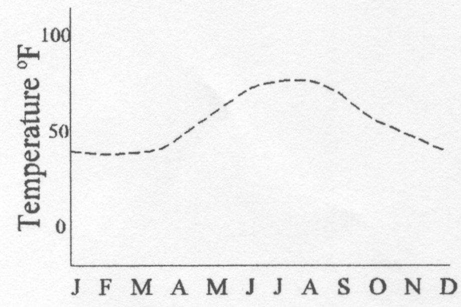


Messinaland

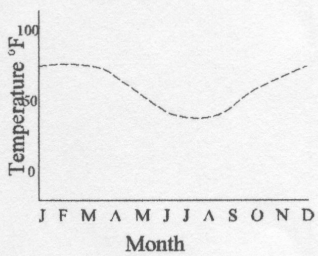


Planetary Wind Belts

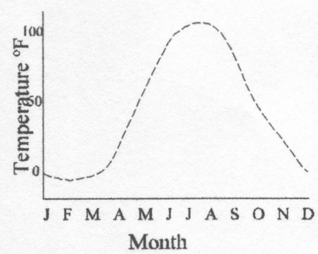
Use the graph below to answer question 31.



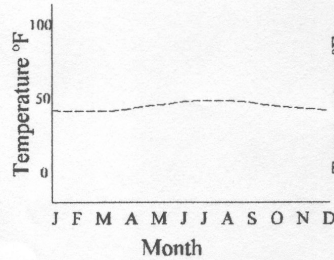
6. If the graph to the right shows the average high temperature for location "A" during a year, which graph most likely shows the average high temperature for location B?



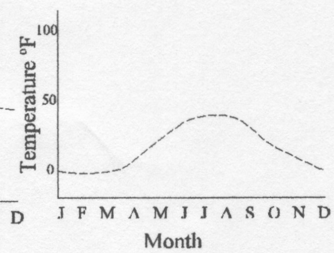
A



B



C



D

7. Which location probably has the driest climate? A, B, C, D

8. Which location lies closest to a known zone of convergence and low pressure? A, B, C, D

as well as the efficacy and methods of instruction. The results of the questionnaires were revealing, and reflective of enrollment diversity. Some students (non-science majors) took the course to satisfy a university-wide science requirement, while others (the current and future high school science teachers) either possessed or were near completion of a science B.S. degree. Although the comments were anonymous, the responses fell into two basic categories, likely reflecting this "dual-purpose" enrollment culture. While most students seemed to feel that the level of difficulty of the material was fair, a few remarked on their surprise at how challenging they found it - "this course was very difficult for me" - while one student admitted: "I felt that the material was just right for me, but I'm a grad student (Master's); I felt it may have been too detailed for undergrads."

Teachers and future teachers were asked whether they planned to use any of the in-class activities in their own classrooms, and every one admitted that they already had! Comments collected from just the non-teachers indicated that they unilaterally found the hands-on approach helpful ("I thought all the activities were useful and helpful in applying course elements"; "I felt that the activities helped the subjects to come alive"; "It helped to learn the material by actually seeing it").

Students were unanimous in their appreciation for the online resources available to them; they found it helpful to print out the notes and activities. Similarly they found the instruction to be effective. Comments about the instructor included: "She made difficult material seem a lot easier than it could have been!"; "(She) kept the information given in digestible amounts"; and "She explained things simply, with real examples and references."

Comments about the level of difficulty of the exams included such statements as: "(They were) the most difficult exams of all my classes this semester"; "I found the exams to be very difficult"; and "They are very hard." The only comment which can be interpreted as being in some way different came from a current science teacher (who volunteered her identity on the questionnaire); she wrote: "I loved the exams! They made you think! While some questions were fairly straightforward, others made you take the information to another level of understanding. Great!"

Among the most flattering comments were from two non-science majors, one who stated that he or she was intending to take additional lab classes in geology, and one who admitted that he or she was contemplating changing majors, and becoming a high school science teacher.

To understand geologic phenomena, one must have the ability to envision three-dimensional processes, and must be able to imagine their progressions over vast amounts of time. This "fourth-dimensional" intellectual capacity is a fairly sophisticated hallmark of a formal operational stage of cognitive development. This level of abstract thought may first evolve in adolescents, but some individuals never achieve this level, even well into adulthood (Piaget and Inhelder, 1958). Could the subject matter itself simply be too difficult for most adolescents, and many adults?

Why then do school districts around the country offer Earth Science to students whose cognitive development is characterized a s being atmore of a "concrete operational" stage? The curriculum needs to be adapted to the linear-reasoning capacities of its audience, and often the topics are necessarily limited to descriptions, identification, or memorization of material. When Earth Science is taught in this concrete-operational manner, it is indeed true to its reputation as "Rocks for Jocks," and the status of Earth Science remains misleadingly low. Hence, when adults enroll in a course on the undergraduate level, their expectations may be unrealistic, and their success is somewhat dependent on whether they have achieved the cognitive skills to grasp abstract thought.

THE UPSIDE-DOWN PYRAMID

Today's high school science sequence was developed over a century ago, when science was far more descriptive and concrete. Since the 1800s, it has been common practice for freshmen to take General Science or Biology, sophomores Chemistry, and juniors Physics. Geology hardly existed as a separate discipline at the time that this structure was first instituted, and now—even despite the plate tectonic revolution—it still remains as an elective at best, or more frequently, as an alternative to the traditional science menu for students of lower academic achievement. According to the National Center for Educational Statistics (2000), in 1998 (the most recent year for which data are available), only 20.7 percent of high school graduates took Geology or Earth Science, compared to 92.7 percent who took Biology and 60.4 percent who took Chemistry. These figures are consistent with those of a survey conducted four years earlier (Smith, 2000), when 24.4 percent of high school students took a geology or Earth science course. If there is any significant trend indicated at all, Earth science courses are becoming less available on the high school level over time.

At the high school level, juniors and seniors who are deemed at a lower academic level were able to excel at the more conceptual topics (such as interpreting contour maps). The "brighter" freshmen had problems with the visualization associated with this exercise. This antiquated progression has been the subject of a relatively recent movement to put Physics first. While only a few schools actually have retrained their teachers and made the difficult transition to ninth-grade Physics, there is increasing consensus that flipping the sequence gives the curriculum a coherence it now lacks, and allows students to build on concepts they have learned (Lewin, 1999). By inverting the traditional succession, students would be given the tools to grasp complex concepts, and by delaying the fourth-dimensional concepts to the junior or senior year, they would more likely have already developed the cognitive skills characteristic of a more mature brain by then.

There is evidence that changing the sequence improves student achievement and interest in science. The number of students successfully completing Advanced Placement courses, and obtaining college credit while still in high school, may be tied directly to the shift in focus. At North Hunterdon High School in Annandale, N.J., for example, there were only 38 students enrolled in any Advanced Placement science class in 1990-91, the last year of the old sequence; the new curriculum has brought steady increases in those numbers, and in 1999, a record 226 students are in Advanced Placement science: 98 in Biology, 49 in Physics, 41 in Environmental Science and 38 in Chemistry (Lewin, 1999).

While there has been a push toward the development of an Advanced Placement course in Earth Science, such a curriculum has not yet been approved. Perhaps we should consider completing the secondary science sequence with Earth Science as the "capstone" course. If students were to take such a course after having been introduced to requisite physical science concepts in Chemistry and Physics, and after learning about the diversity of life on Earth in Biology, Earth Systems Science may seem to be a natural finale, providing the student with a cohesive culmination of what may otherwise be viewed as discrete, disjointed disciplines.

CONCLUSIONS

The unplanned experiment in which a high-school level earth science curriculum was presented to college juniors and seniors is revealing in many ways. First, it confirms the difficulty of a science that has traditionally been viewed as the one of the least challenging options at the college level. Second, it validates that most people arrive at college with little or no prior knowledge in the geosciences, a failing of our current K-12 science requirements and sequencing. And third, it suggests that Earth Science may be best suited for pre-college students who have mastered physical/biological science foundations, and have attained the ability to reason and think abstractly. It is clear that Earth Science should not be relegated solely to earlier grades, or solely to under-achievers; it needs to be viewed as a culminating course, offering its students the ability to tie in prior knowledge with widely-observed everyday geoscience applications.

The under-representation of Earth Science at the high school level is a reflection, in part, of the shortage of well-prepared teachers. Courses such as Geology 103 and professional development programs such as BAESI and BASEE are needed to help bridge the "preparation gap," and yet more needs to be done.

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