Teaching Methods in Undergraduate Geoscience Courses: Results of the 2004 On the Cutting Edge Survey of U.S. Faculty

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ABSTRACT

A survey of U.S. geoscience faculty provides an integrated look at the geoscience courses currently being taught and the teaching methods that are used in these courses. The survey data indicate that there is a wide array of offerings both at the introductory level and for majors and thus no standard geoscience curriculum. While teaching methods remain dominated by lecture, most faculty use a range of more interactive methods. Most students are asked to solve problems including quantitative ones as part of their courses although relatively few explore problems of their own choosing. Writing and reading in the primary literature are used extensively in courses of all sizes at both the introductory level and in courses for majors. Strategies and tools for assessing student learning are strongly dependent on class size; however, students are more likely to be assessed through problem sets, oral presentations or papers in courses for majors. There is no question that research on learning and the resulting recommendations for best classroom practice that have emerged over the past decade have had an impact on geosciences classes. On the other hand, there is room for growth. Our data suggest that most faculty are still using these techniques infrequently. These results strongly support the continued offering of professional development activities that both bring new ideas to faculty and address the practicalities of widespread implementation of these techniques.

INTRODUCTION

Undergraduate science education plays a pivotal role in the nation's educational system as the venue in which the science workforce initiates its training, teachers receive their formal education in science, and a large portion of the general public takes its highest level courses in science. The importance of excellent instruction in undergraduate science courses has received increased attention in the context of this pivotal role (NSF, 1996; NRC, 1997; Ireton and others, 1997; NRC, 1999; NRC, 2000). Attention has focused particularly on the methods of instruction, the need to engage students in learning, and the importance of instruction that encompasses both scientific knowledge and the process of scientific inquiry. While the geoscience community has responded with increased interest in discussing educational advances, we have lacked to date a national perspective on the nature of instruction in undergraduate geoscience courses. To shed light on this important question, we undertook a nationwide survey of geoscience faculty during the spring of 2004.

The survey was developed as part of On the Cutting Edge, a professional development program for faculty that is sponsored by the National Association of Geoscience Teachers (NAGT) and funded by the NSF CCLI-ND program; (for further information about On the Cutting Edge visit http://serc.carleton.edu /NAGTWorkshops). The Statistical Research Group of the American Institute of Physics (AIP) assisted in development of the survey and was responsible for its administration and data reduction. The survey addressed three questions that lie at the heart of geoscience teaching: 1) how are faculty teaching undergraduate geoscience courses? 2) how do faculty learn about the content and methods that they use in their teaching? and 3) how do faculty share with their colleagues what they learn about teaching? In this paper, we focus on the responses associated with the first question.

An intriguing snapshot of faculty approaches to undergraduate geoscience education in 2003 emerges from the data. Both introductory courses and courses for majors have titles reflecting a diversity of approaches to teaching about the Earth system. Despite the fact that traditional lecture still dominates undergraduate teaching in the geosciences, particularly in large introductory courses, most faculty are trying techniques that move beyond traditional lecture to engage learners in classes of all sizes. Problem solving, including quantitative problems, is important to faculty and problem-solving activities are widely used. Students read the primary literature in courses throughout the curriculum, and are asked to write papers in classes of all sizes.

This paper is written first and foremost for faculty. It is an opportunity to move beyond anecdote and learn what others are doing nationwide. We hope it opens up possibilities for faculty to try things they might have thought impossible by providing the knowledge that others are exploring and experimenting with a variety of instructional strategies. The second audience for the paper includes those who run professional development workshops and programs. While this survey does not measure change or the impact of such programs, it does provide evidence that methods and ideas advocated by

Response	Number of Responses	
Part 1 of Survey		
Taught introductory courses only		354
In Part 2 gave details about introductory coureses taught	293	
Dropped out of survey before completing Part 2	61	
Taught courses for majors only		432
In Part 3 gave details about coureses for majors	376	
Dropped out of survey before competing Part 3	56	
Taught both introductory and coures for majors		1063
Answered Part 2 of Survey - details about introductory courses	521	
Answered Part 3 of Survey - details about courses for majors	444	
Dropped out of survey before completing either Part 2 or Part 3	98	
Taught graduate level coures only		177
Taught NO courses during either spring 2003 or fall 2003		176
Did not answer teaching assignment question		5
Total number of respondents to Part 1 of Survey		**2,207**
Part 2 of Survey		
Responses for introductory coureses (see 293 + 521 above)	814	
Faculty who responded about two different introductory courses	41	
Faculty who responded about four different intordutory coureses	1	
Total different introductory coures included in survey	**858**	
Part 3 of Survey		
Responses for majors courses (see 376+444 above)	820	
Faculty who responded about two different coureses for majors	108	
Faculty who responded about three different courses for majors	2	
Total different courses for majors included in survey	**932**	

Table 1. Responses to questions about teaching assignments for introductory, majors, and graduate-level courses, and follow-through responses in subsequent questions. Responses reflect courses taught during spring 2003 and fall 2003, with each term counted separately.

educational and cognitive researchers are being adopted by geoscience faculty. It also serves as a baseline for future studies of programmatic impact.

SURVEY DESIGN AND ADMINISTRATION

Survey design, administration, and interpretation require substantial expertise to obtain useful information that is valid and robust. To bring such expertise to this study, we partnered with the Statistical Research Center of the American Institute of Physics, which been conducting surveys of science education for over 40 years. In this section, we describe the process that led to the particular survey questions, the data collection methods, and the analysis that indicates how closely our sample represents the total population of geoscience faculty.

The Survey Questions - Our goal in this survey was to determine three things:

1) What methods, activities, and assessments are faculty using in geoscience courses? This information provides a snapshot of current classroom practice and reflects the current level of expertise in the community. It also serves as a baseline against which to measure the impact of professional development programs on teaching practice.
2) How do faculty learn about new content and teaching methods? This information explores how faculty ensure that their courses have up-to-date content delivered with the most appropriate teaching techniques. A primary goal of On the Cutting Edge and other professional development programs is to facilitate this learning. Understanding the work habits of faculty illuminates the design of workshops and web products.
3) How do faculty contribute the things they learn about teaching back to the community? This sharing is a measure of the health of the geoscience education community as it enables the community as a whole to learn and improve. Professional development programs play an important role in both encouraging and providing opportunities for this type of exchange.

With these questions in mind, the authors drew on their own knowledge to identify specific areas of interest and potential survey questions. A survey of biology faculty (First II, 2002) was used as a starting point in identifying teaching methods. Questions regarding teaching with data rest heavily on observations reported in Using Data in the Classroom (Manduca and Mogk, 2002). The questions were tested for clarity in a field test

Course Subject	Respondents indicateing one or more courses of this type		Total number of courses reported by each type	
	Number	Percent	Number	Percent
Earth Science	196	16	306	16
Earth System Science	86	7	114	6
Environmental Geology	117	10	168	9
Historical Geology	107	9	140	7
Meteorology	45	4	76	4
Oceanography	106	9	169	9
Physical Geology	240	20	385	20
Other	314	26	535	28
Total	**1,219**	**100**	**1,893**	**100**
Course types within the category "Other"	**Respondents indicating one or more courses of this type**			
	Number	Percent		
Atmospheric Science and Climate	13	1		
Earth Materials, Solid Earth	10	1		
Earth Resources	8	1		
Environmental Science	45	4		
Field Course	7	1		
Geo/Science for Special Audiences	8	1		
Geography	41	3		
Hazards	23	2		
Hydrology	5	0		
Lab Only	5	0		
Non-Geoscience	29	2		
Oceans, Coasts, Geomorphology	5	0		
Paleontology/Historical Geology	26	2		
Physical Science/General Studies	20	2		
Place-based Courses	10	1		
Planetary/Space Science	39	3		
Science and Society	8	1		
Soil	12	1		
Other Total	**314**	**26**		

Table 2. Types of introductory courses taught by faculty during spring 2003 and fall 2003. The left column gives the number of facutly reporting teaching one or more courses of each type. The right column is the total number of courses reported.

of the survey taken by sixteen faculty and short interviews with five faculty at the American Geophysical Union Fall Meeting in 2002 and were revised appropriately.

One of the most difficult concepts in designing the survey was the link between methods and courses. We were interested in the scope of methods used by an individual faculty member across their teaching, as well as the range of methods experienced by a student in a single class. In addition, we wanted to explore the relationships among methods, course size, and content. To address these relationships, the survey asked respondents to describe methods in a specific course that they had taught recently. Respondents were allowed to submit data from more than one course. With this design, the course, not the faculty member, is the central unit of measure in our findings, and all of the results are presented as the percentages of courses in which students experience different types of teaching methods, activities, or assessments.

The survey contained six parts: 1) years of teaching, type of institution, geoscience specialty, and other demographics; 2) teaching and assessment practices in introductory courses; 3) teaching and assessment practices in courses for majors, 4) strategies for learning new geoscience content and teaching methods, 5) contributions to the geoscience education community; and 6) department demographics. Questions from parts 1, 2, and 3 are available at <http://serc.carleton.edu /NAGTWorkshops/survey/questions.html>.

The survey was administered via a web-based form. To reduce the time required for each participant to

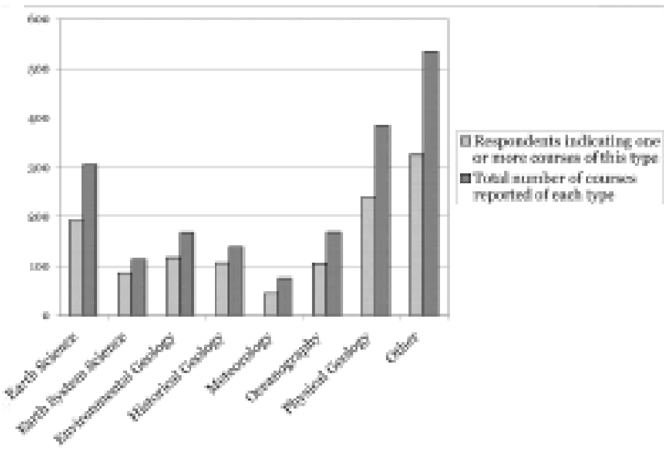

Figure 1. Types of introductory courses taught by faculty during spring 2003 and fall 2003. The left column gives the number of faculty reporting teaching one or more courses of each type and the right column is the total number of courses reported.

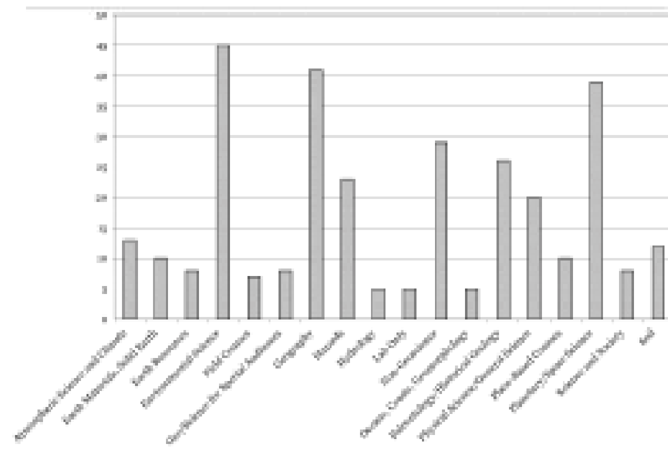

Figure 2. Numbers of introductory courses categorized as "Other" in the geosciences survey taught by faculty during spring 2003 and fall 2003.

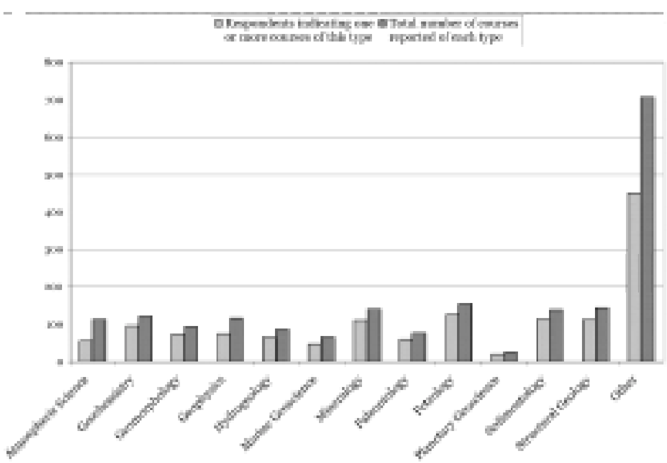

Figure 3. Types of majors classes taught by faculty during spring 2003 and fall 2003. The left column gives the number of faculty reporting teaching one or more courses of each type and the right column is the total number of courses reported.

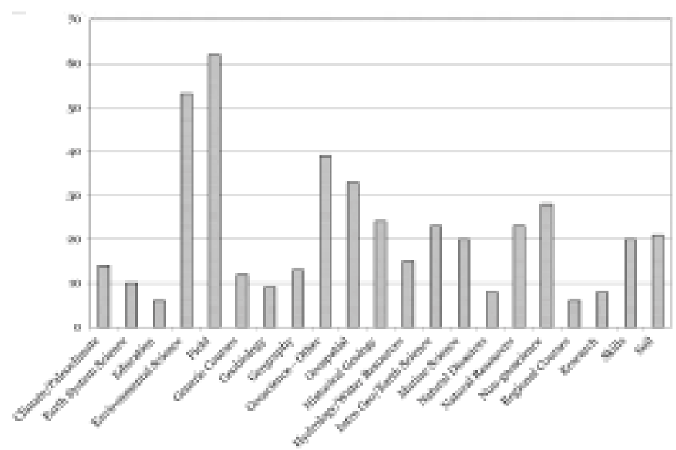

Figure 4. Numbers of majors courses categorized as "Other" in the geosciences survey taught by faculty during spring 2003 and fall 2003.

complete the survey, participants were directed to complete either part 2 or 3 based on their recent teaching responsibilities. Questions in part 1 determined if a participant had recently taught either introductory courses or courses for majors. Respondents teaching only introductory courses answered questions in part 2. Those teaching only courses for majors answered questions in part 3. Faculty teaching both introductory courses and courses for majors were randomly assigned to answer questions either in part 2 or in part 3. All respondents to parts 2 and 3 were directed to questions in parts 4 and 5. Only department chairs responded in part 6. The numbers of respondents to the first three parts of the survey are shown in Table 1.

The Survey Sample - The goal of the study was to obtain information from the largest possible number of faculty who teach geoscience, atmospheric science, and ocean science in the United States at the full spectrum of undergraduate institutions (private and public universities, two-year and four-year colleges). To reach this population, a list of 7435 names and email addresses was developed with the assistance of the American Geological Institute which publishes the Directory of Geoscience Departments.

These faculty received an e-mail in May 2004 requesting them to complete the on-line survey. We received approximately 1200 notifications of bounced messages following the initial mailing. An unknown additional number of messages were never delivered by servers that do not notify senders if e-mail addresses are no longer working. 520 faculty declined to fill out the survey because they had retired or do not teach undergraduate courses. We estimate that our survey request reached at most 5700 faculty who teach undergraduate geoscience.

After three email deliveries urging a response to the survey, we received 2207 responses, a response of 39% based on 5700 initial requests. The response rate is likely higher than this, as we do not know the total number of

Course Subject	Respondents indicating one or more courses of this type		Total number of courses reported of each type	
	Number	Percent	Number	Percent
Atmosphereic Science	56	4	113	6
Geochemistry	96	7	121	6
Geomorphology/Surface Processes	73	5	94	5
Geophysics	75	5	116	6
Hydrogeology	65	5	87	4
Marine Geoscience	47	3	66	3
Mineralogy	111	8	140	7
Paleontology	61	4	77	4
Petrology	126	9	155	8
Planetary Geoscience	20	1	26	1
Sedimentology/Stratigraphy	114	8	138	7
Structural Geology/Tectonics	112	8	144	7
Other	451	32	707	36
Total	**1,407**	**100**	**1,984**	**100**

Course types within the cateogry "Other"	Respondents indicating one or more courses of this type	
	Number	Percent
Climate/Paleoclimate	14	1
Earth Systems Science	10	1
Education	6	0
Environmental Science	53	4
Field	62	4
geobiology	9	1
Geography	13	1
Geoscience - Other	39	3
Gespatial (e.g. GIS, GPS)	33	2
Historical Geology	24	2
Hydrology/Water Resources	15	1
Intro Geo/Earth Science	23	2
Marine Science	20	1
Natural Disasters	8	1
Natural Resources	23	2
Non-discipline specific	12	1
Non-geoscience	28	2
Other	4	0
Regional Courses	6	0
Research	8	1
Skills	20	1
Soil	21	1
Other Total	**451**	**32**

Table 3. Types of majors courses taught by faculty during spring 2003 and fall 2003. The left column gives the number of faculty reporting teaching one or more courses of each type. The right column is the total number of courses reported.

faculty who either never received the e-mail or who received a survey and declined to fill it out because they do not teach undergraduate geoscience courses.

Whereas the 39% return on our survey gives us confidence that the results reflect a significant fraction of geoscience faculty in the U.S., we acknowledge the possibility that those who chose to fill out the survey are preferentially interested in education and are acquainted with the sponsoring program. As a definitive number describing the geoscience faculty population is not available, we cannot determine the percentage of total geoscience faculty in the U.S. who responded to the survey.

The 'Year of Degree' reported by respondents shows a uniform distribution. When the data are collapsed into five-year groups, only the responses from the first five-year increment is significantly smaller than other increments up to '35 or more' years from degree. This may reflect significant numbers of recent PhDs taking postdocs or a time lag between appointment and appearance in the AGI Directory database. Similarly, the sample is 50% full professors, 28% associate professors and 16 % assistant professors. Lecturers, adjunct faculty, and other make up 6% of the sample. These data confirm that the sample includes significant numbers of responses from faculty in all stages of their careers and that the web-based delivery did not induce an age bias.

The sample is dominated by faculty reporting geology or geophysics as their disciplinary focus (65%). Ocean Science and Atmospheric Science compose 12% and 6% of the sample respectively, with 17% of faculty reporting other disciplinary foci. This pattern may reflect the abundance of geology and geophysics faculty in geoscience departments, the historical origins of the AGI Directory in geology, or the location of faculty with specialties in Ocean and Atmospheric Science in non-geoscience departments making them difficult to identify for the survey. Department chairs are overrepresented in the sample: 55% of department chairs completed the survey as opposed to 39% of faculty overall.

SURVEY RESULTS

This paper presents the results from the first third of the survey addressing the teaching of geoscience in the U.S. The relevant survey questions are available at <http://serc.carleton.edu/NAGTWorkshops/survey/questions.html>. These questions were chosen to illuminate the complete learning experience of a student in a geoscience course. In specific, the data address four questions:

What courses are geoscientists teaching? We draw conclusions about the current breadth of geoscience instruction and address questions such as: How common are Earth system science courses? Are emerging research interests (e.g., biogeoscience) revealed in course titles?

What teaching methods are faculty using? We ascertain how closely classroom instruction reflects current understanding of the learning process and address questions such as: Does classroom instruction reflect the need to actively engage students with the content? Are faculty motivating students learning by placing problems in a context that is meaningful?

What kinds of activities do faculty ask their students to engage in? These data illuminate how faculty engage students in executing the skills they are trying to teach. We are particularly interested in the roles that problem-solving, quantitative reasoning, and writing play in courses.

What kind of assessment strategies do faculty use? These data provide insight into how faculty ascertain what students are learning. Assessment results are a critical piece of the feedback that faculty use to understand the impact of their teaching on student learning. At the same time, assessments drive student learning both through their role in assigning grades, a primary motivator for many students, and as an explicit measure of the value faculty place on different types of student achievement. While the survey gives no information on the content of such assessments, it does allow us to understand the breadth of tools that are in use across the country in courses of various sizes and to interpret the importance that is placed on writing, speaking, and problem-solving in various parts of the curriculum.

What Courses Are Geoscience Faculty Teaching? - Respondents were asked to classify the courses they taught in spring and fall 2003 at either the introductory level or for majors by selecting from a list of common courses (e.g., Physical Geology, Earth Science, Oceanography, Mineralogy, Hydrogeology) or indicating "Other" and providing a phrase describing their courses. Courses classified as other have been grouped on the basis of these phrases. The aggregated data are shown in Tables 2 and 3 and Figures 1 to 4. The individual responses are available at http://serc.carleton.edu/NAGTWorkshops/survey/other_courses.html.

Summary - The survey results indicate that the geoscience curriculum is very diverse. In addition to the offerings typically associated with a geoscience curriculum, faculty are teaching a wide range of topical courses reflecting topical approaches to teaching at both the introductory level and in courses for majors. The most important results are summarized below.

- Physical Geology, Historical Geology, and Earth Science remain mainstays of the introductory curriculum; they comprise 44% of introductory courses reported. The most commonly reported courses for majors are mineralogy, petrology, sedimentology/stratigraphy, and structural geology/tectonics.
- 26% of introductory courses and 32% of courses for majors were categorized as "Other" by faculty; that is they could not be classified in the list of options provided in the survey. No single grouping within the "Other" category constitutes more than 5% of the whole indicating a very diverse group of courses.
- Introductory courses with an environmental focus are common; these include those in the Environmental Geology category, courses on environmental topics within the "Other" category, and courses focused on topical issues (e.g. global change, hazards, and earth resources).
- Courses for majors that are related to relatively recent topics in geoscience research are indicated by the course titles (e.g., Geobiology, Climate Change).
- Field mapping and methods courses are reported frequently and are dominated by geology. Field courses in geography and remote sensing are also reported.

Discussion - A major feature of the geoscience curriculum is the lack of a standard set of course offerings either at the introductory level or in the curriculum for majors. At the introductory level, we see both the continued offering of traditional survey courses, such as physical geology, historical geology, environmental science and Earth science, and a diverse set of topical courses including

- thematic courses such as planetary geology and plate tectonics,
- courses focused on the geoscience of a particular area (Geology of Alaska/Hawaii/New Mexico; National Parks), and
- courses for a specific audience (pre-service teachers, engineers). Courses for majors show a similar diversity, where one-third of the courses reported are those reflecting emerging research and technical areas and recombinations of traditional material.

The use of an Earth system approach was recommended in 1997 (Ireton and others) as a mechanism for helping students understand the interconnectedness of all aspects of the geosciences. Our data show that course offerings provide an opportunity for students, including introductory students, to study the entire Earth system (ocean, atmosphere, solid Earth). There are a number of introductory courses classified as Earth system science which likely take an integrated approach to the studying the parts of the Earth system. NASA established the Earth System Science Education program in 1991 to facilitate implementation of this approach.(e.g., Earth System Science Education in the 21st Century, http://esse21.usra.edu/). Titles of courses for majors, such as Earth System Modeling, Climate Change, and Biogeochemical Cycles indicate that majors in some departments have an opportunity to learn about the integrated Earth system as well as its connections to the biosphere.

Course titles also suggest that some majors have an opportunity to learn about research of current interest. For example, courses are reported in Geomicrobiology, Geoarcheology, Forensic Geology. Interestingly, planetary science is much more extensively offered at the introductory level. The titles of introductory course (e.g., Astrobiology) hint at the incorporation of current research at this level as well.

The geosciences prepare students for a broad spectrum of employment opportunities and the nature of those jobs has changed substantially in recent decades (AGI, 2004). The course offerings for majors include courses appropriate for traditional employment sectors in mining, petroleum, and weather forecasting (e.g. Mining Engineering, Mineral Deposits, Petroleum Geology, and offerings classified as Atmospheric Science). There are also a large number of hydrogeology and environmental courses such as Environmental Chemistry and Physical Hydrology that would prepare students for jobs in the environmental sector. A number of courses for majors emphasize use of technology needed for current employment such as geospatial analysis (GIS, GPS, remote sensing), advanced methods (e.g. geochemistry, geophysics), and other computer applications (modeling). Skills commonly requested by employers are reflected in course titles focused on skills such as writing and geostatistics. Finally, faculty reported teaching courses that are not typically thought of as geoscience courses (e.g. analytical chemistry, fluid mechanics). These courses may reflect faculty teaching in integrated science departments, faculty with joint appointments, or a wide range of other circumstances. They suggest that many students in the geosciences have opportunities to interact with faculty who have expertise that spans multiple disciplines. While it is difficult to infer too much from course titles, the breadth of the courses offered, the focus on technology and skills, and the opportunity for interdisciplinary training bode well for preparing students to work in an environment dominated by interdisciplinary teams and relying heavily on modern technology.

Course offerings in atmospheric science and ocean sciences are relatively rarely reported in the survey results as compared to geology courses. This may reflect that these are areas of expertise that are developed primarily at the graduate level. 40% of faculty who identified themselves as oceanographers taught only graduate level courses or did no teaching. The low number of courses reported may reflect the sample population, which as described earlier is dominated by geologists and geophysicists. Nonetheless, students have fewer opportunities to be introduced to ocean and atmospheric science in the introductory and majors curriculum.

In sum, the geoscience curriculum is characterized by diversity. Geoscience faculty are teaching a large number of courses, distributed over a broad range of topics. The diversity of courses reported confirms that geoscience does not have a standard curriculum but rather that departments take a wide variety of approaches based on different departmental missions, faculty strengths, student needs. This diversity most likely serves the geosciences well given both the variety of employment opportunities and the scope of the scientific discipline.

Course Size - As might be expected, there is substantial range in the size of introductory courses. We have divided the data into three groups (small courses 30 or fewer students; medium courses 31-80 students; large courses of greater than 80 students). These groups were chosen to place approximately 1/3 of the results for introductory courses in each group. We used the same size groups for courses for majors. Most of the majors courses (89%) are small (30 students or fewer) and the remainder are medium sized (31-80 students).

As will be seen below, course size has a substantial impact on teaching. These data indicate that while roughly 1/3 of introductory courses are small and 1/3 are large, most students will be in large introductory courses. In contrast, most courses for majors are small and most majors will be in small courses. While this comes as no surprise, it reiterates that the instructional setting for introductory courses is very different than that for courses for majors.

What is the Current State of Classroom Teaching in the Geosciences? - One of the main aims of this survey is to capture a picture of what faculty and students do in geoscience courses. We are particularly interested in the extent to which faculty use interactive teaching methods, teach with data, and assess student learning. We have divided the results about classroom teaching into three sections reflecting three sets of survey questions: teaching methods and techniques, student activities in the classroom, and assessment strategies.

Teaching Methods and Techniques - The results of the teaching methods portion of the survey appear in Figure 5 and Table 4 with results broken out by course size (small courses <31 students; medium courses 31-80

Table 4. Faculty use of teaching strategies.	**Never %**	**Once or Twice %**	**Several Times %**	**Weekly %**	**For Nearly Every Class %**
Traditional Lecture					
Small Introductory Class (30 students or fewer)	11	6	11	21	51
Medium Introductory Class (31-80 students)	7	3	4	16	70
Large Introductory Class (81 students or greater)	7	1	5	12	75
Small Majors Class (30 students or fewer)	10	4	8	22	56
Medium Majors Class (31-80 students)	9	3	9	24	55
Lecture/Individual answers					
Small Intro Class	14	14	16	20	36
Medium Intro Class	11	10	17	25	37
Large Intro Class	15	12	24	15	34
Small Majors Class	11	12	21	21	35
Medium Majors Class	19	8	21	22	30
Lecture/entire class answers					
Small Intro Class	34	18	18	11	19
Medium Intro Class	28	15	21	16	20
Large Intro Class	36	12	18	14	20
Small Majors Class	36	16	17	15	16
Medium Majors Class	39	14	17	16	14
Whole-class discussion					
Small Intro Class	20	21	28	16	15
Medium Intro Class	29	22	28	14	7
Large Intro Class	45	21	21	8	5
Small Majors Class	23	20	26	18	13
Medium Majors Class	29	25	26	15	5
Lecture with demonstration					
Small Intro Class	19	17	31	22	11
Medium Intro Class	13	21	28	22	16
Large Intro Class	15	24	26	21	14
Small Majors Class	18	17	28	23	14
Medium Majors Class	17	22	26	23	12
In-class exercise					
Small Intro Class	29	22	22	18	9
Medium Intro Class	38	22	21	15	4
Large Intro Class	48	15	22	9	6
Small Majors Class	27	20	26	20	7
Medium Majors Class	37	22	25	11	5
Small group discussion					
Small Intro Class	46	14	18	14	8
Medium Intro Class	55	17	18	6	4
Large Intro Class	65	11	12	6	6
Small Majors Class	51	16	17	9	7
Medium Majors Class	53	15	21	7	4
Fieldwork					
Small Intro Class	47	25	21	4	3
Medium Intro Class	62	27	8	3	0
Large Intro Class	73	20	6	1	0
Small Majors Class	40	28	20	8	4
Medium Majors Class	48	24	21	6	1
Classroom debates/role-playing					
Small Intro Class	68	17	10	3	2
Medium Intro Class	73	16	8	2	1
Large Intro Class	83	11	5	1	0
Small Majors Class	83	8	6	1	2
Medium Majors Class	81	8	8	1	2

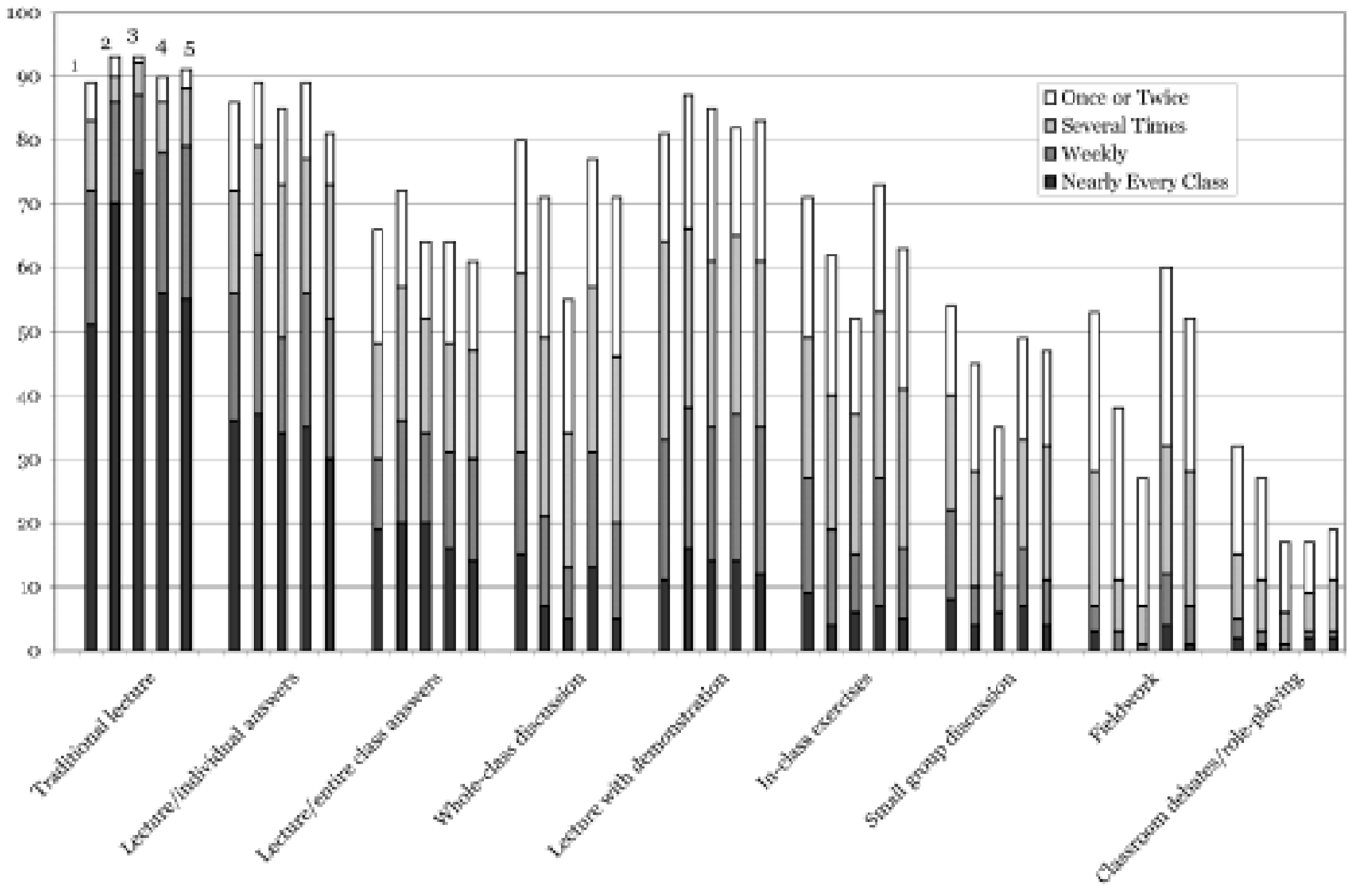

Figure 5. Faculty use of the teaching strategies for both introductory and majors classes, across all class sizes, reported as percent. Columns are groups in fives, and indicate the following classes for all strategies: 1: small introductory class (30 students or fewer), 2: medium introductory class (31-80 students), 3: large introductory class (81 students or more), 4: small majors class (30 students or fewer), 5: medium majors class (31-80 students).

students; large courses >80 students) and by course type (introductory vs. courses for majors).

Summary - Survey results reveal that geoscience faculty across the country use a variety of teaching methods in courses across the undergraduate curriculum. In addition to giving lectures, faculty in both introductory courses and courses for majors employ activities ranging from in-class exercises to classroom debates to role-playing. The most important results are summarized below:

- Even though traditional lecture is the most commonly-used classroom teaching method, only 66% of faculty teaching introductory courses and only 56% of faculty teaching courses for majors report using it in nearly every class.
- More than half of the respondents incorporate some interactive activities into their classes weekly or more often. Most commonly, respondents use questioning, demonstrations, discussions, and in-class exercises. Less commonly, faculty use small group discussion or think-pair-share. This result is similar to that for faculty across the disciplines who show widespread adoption of class discussion (Lindholm and others, 2002).
- It is clear, however, that most courses are fundamentally lecture-based. Less than 1/3 of respondents use interactive techniques other than lecture with questions or lecture with demonstrations more frequently than several times a semester.
- Not surprisingly, interactive techniques are used more frequently in small introductory courses and in courses for majors, of which 89% of those reported are small.

Discussion - While almost all faculty report giving traditional lectures, we find it striking that so many faculty incorporate some interactive activities into their courses (Figure 5). Even the interactive teaching method used by the fewest number of faculty - classroom debates or role-playing - is used by 22% of faculty at least once a term. This suggests that many faculty know about and are willing to use the kinds of interactive teaching methods that have been promoted over the past decade in geoscience education reform. This result is similar to those found in surveys of college faculty which show a general increase over time in interactive teaching techniques and a decrease in lecturing (Lindholm and others, 2002).

We should emphasize, however, that the numbers above indicate use at least once per term. In a course that

Course Type	Local Problem %	National/ Global Problem %	Guided Problem %	Posed/ Solved Own Problem %	Little Guidance %	Online Data %	Collect Data %	Online Tools/ Own Data %	Data with Primary Lit. %
Small Intro	32	55	74	19	60	44	43	14	40
Medium Intro	34	58	76	14	61	44	34	13	36
Large Intro	30	54	73	10	49	41	24	13	28
Small Majors	29	32	84	22	71	39	55	18	56
Large Majors	27	52	80	14	64	53	38	20	46

Table 5. Types of problem solving activities completed in both introductory courses and courses for majors, across all class sizes, reported as percent.

	Never %	Once or Twice %	Several Times %	Weekly %	Nearly Every Class %
Read Primary Literature					
Small Intro	34	27	20	11	8
Medium Intro	43	25	13	9	11
Large Intro	55	22	8	7	8
Small Majors	14	29	35	14	8
Large Majors	20	30	30	15	5
Quantitative Problem Solving					
Small Intro	15	22	36	22	5
Medium Intro	15	22	37	22	4
Large Intro	18	27	35	17	3
Small Majors	9	14	32	35	10
Large Majors	9	16	37	29	9
Online Problems Sets					
Small Intro	63	14	15	8	0
Medium Intro	55	19	15	9	2
Large Intro	53	17	14	14	2
Small Majors	68	16	9	6	1
Large Majors	62	13	12	12	1
Structured Collaborations					
Small Intro	31	22	28	14	5
Medium Intro	44	20	22	11	3
Large Intro	48	16	21	14	1
Small Majors	31	23	26	15	5
Medium Majors	31	23	28	13	5

Table 6. Frequency of faculty use of other classroom activities (reading priamary literature, solving quantitative problems, solving online problem sets and or using structured collaboration to solve problems) in introdcutory and majors courses.

meets 35-40 times in a semester, one use is not a large percentage of instructional time. The survey shows that fewer than 25% of respondents use any of the listed interactive techniques other than lecture with questions or lecture with demonstrations more frequently than several times a semester. The percentage is only slightly higher (about 30%) if only small and medium courses are considered. In short, faculty appear to be aware of how to develop and use interactive teaching methods, but most do not use them very often.

Survey results show clearly that use of interactive techniques such as small group discussion, whole-class discussion, debates, role-playing, and in-class exercises is not measurably different in small courses than it is in medium-sized ones nor is it different in courses for majors and in introductory courses (Figure 5). Use of interactive techniques in geosciences courses is clearly not confined to small courses nor to courses for majors. These results for medium-sized courses should encourage faculty members who teach such courses that

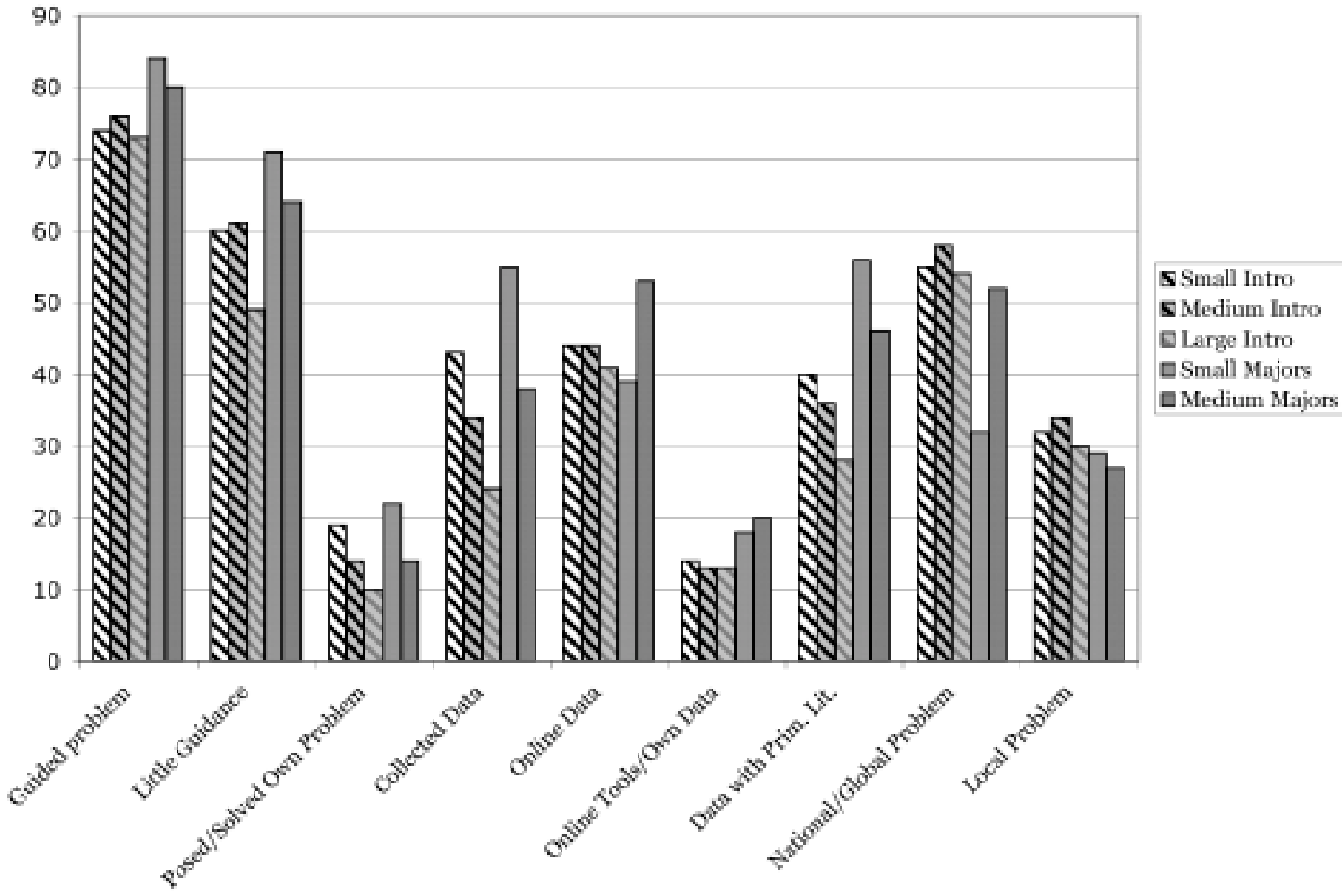

Figure 6. Types of problem solving activities completed in both introductory courses and courses for majors, across all class sizes, reported as percent. Columns are grouped in fives, and indicate the following classes for all problem-solving activities: 1: small introductory class (30 students or fewer), 2: medium introductory class (31-80 students), 3: large introductory class (81 students or more), 4: small majors class (30 students or fewers), 5: medium introductory class (31-80 students).

interactive teaching methods are indeed do-able in courses other than small courses.

Although faculty who teach large introductory courses use interactive techniques much less frequently than faculty who teach smaller courses, we are struck by the number who do use what many consider to be "impossible" techniques in large courses. Of those teaching large classes, 55% use all-class discussion at least once a term, 52% use in-class exercises at least once a term, and 17% even use classroom debates and role-playing at least once a term.

The one area where a difference can be seen in the use of interactive techniques between introductory courses and courses for majors is in the use of role playing and debate. The data indicate that while extensive use of these methods is similar in introductory courses for majors, role playing and debate are used much more extensively on an occasional basis in introductory courses. This may indicate that faculty consider these methods to be more suitable for students being introduced to geoscience and its role in society. It is interesting that these methods are not more extensively reported in courses for majors given the important role that debate plays in the scientific process.

The data indicate widespread use of field activities in the lecture portion of the course. These results reflect clearly the importance that geoscientists place on field observations. However, we are concerned that these data may include a mixture of people limiting their response to the lecture portion only and those considering the full class. Thus this number may overestimate the use of field activities in lecture and underestimate the overall use of field activities. It is thus difficult to interpret.

In sum, while lecture dominates undergraduate geoscience teaching, the data indicate that most faculty have taken some steps to integrate activities that assist students in engaging with concepts presented in the lecture portion of the class. These activities are less frequently reported as a regular part of students' classroom experiences, suggesting that while faculty are aware of these techniques, they are facing barriers to widespread incorporation in their teaching.

Student Activities - Survey results reveal that geoscience faculty across the country ask their students to do much more than attend class. The results of the student activities portion of the survey appear in Tables 5 and 6 and Figures 6 and 7.

Summary - Students in both introductory courses and courses for majors are asked to take part in a wide variety of activities that actively engage them in problem-solving, critical thinking, and working with data. These activities include data analysis, using quantitative skills, working with data and primary literature, and structured collaboration. The most important results are summarized below:

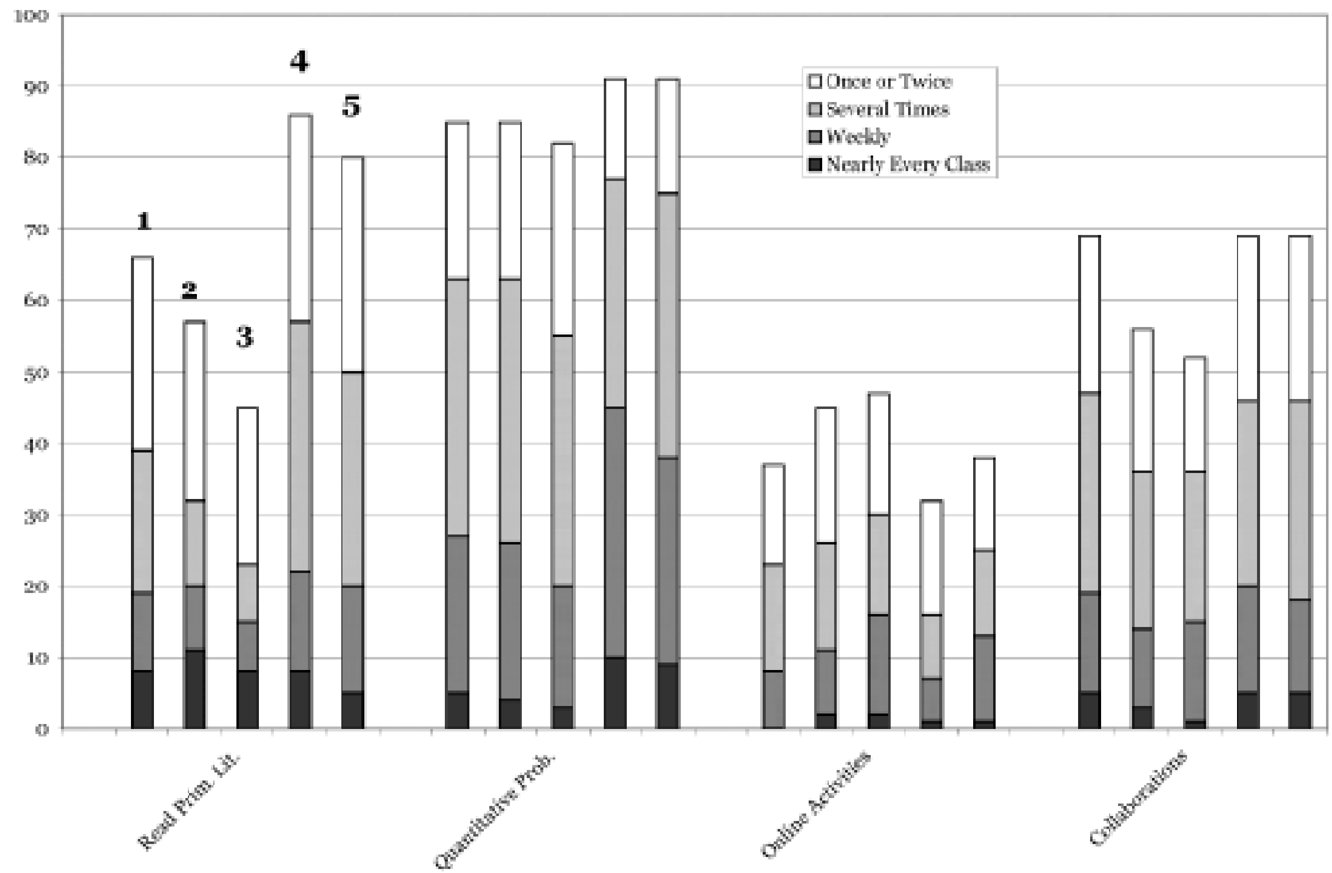

Figure 7. Frequency of faculty use of other classroom activities (reading primary literature, solving quantitative problems, solving online problem sets and/or using structured collaboaration to solve problems) in introductory and majors courses. Columns are grouped in fives, and indicate the following classes for all activities: 1: small introductory class (30 students or fewer), 2: medium introductory class (31-80 students), 3: large introductory class (81 students or more), 4: small majors class (30 students or fewer), 5: medium majors class (31-80 students).

- Problem-solving is important in a large percentage of courses. Faculty in approximately 75% of introductory courses surveyed and nearly 85% of courses for majors ask students to do guided problem-solving and data analysis.
- In contrast, courses that engage students in posing and solving their own problems are rare. Students in less than 20% of courses are engaged in independent problem-posing and solving, regardless of course size or type.
- Students collect their own data and then analyze the data in both introductory courses and courses for majors. However, the use of data collection activities is strongly dependent on class size and occurs more frequently in courses for majors.
- On-line data is used more frequently in introductory courses than in courses for majors. On-line data is used most frequently in large courses for majors where student collection of data may be difficult.
- Quantitative problems are widely assigned in both introductory courses and courses for majors. Only 10% of courses for majors and 16% of introductory courses lacked quantitative problems. More than 55% of faculty ask students to solve quantitative problems at least several times a semester.
- Many students are engaged in problems of local, national or global interest. More than 50% of faculty ask students in introductory courses to address a problem of national or global interest, and 1/4 to 1/3 have students in all courses work on problems of interest to the local community.
- Students in both introductory courses and courses for majors are asked to read primary literature. A majority of introductory courses and 80% of courses for majors ask students to read in the primary literature at least once during the semester. In 35% of introductory courses and 55% of courses for majors students are asked to use this information in their interpretations of data.
- Approximately 1/2 of all large introductory courses engage students in structured collaborations to solve problems at least once a semester. About 2/3 of small to medium-sized courses regardless of type engage students in structured collaborations at least once a semester.

Discussion - Problem-solving and data analysis are important aspects of geoscience courses across the country. The aggregated responses across all sizes and types of courses show that students are engaged in both guided and independent problem-solving in well more than half of courses overall (Figure 6). We caution that there may be substantial variation in individual faculty members interpretation of what constitutes a problem-solving activity. Given the important role of problem-solving in science, faculty may also tend to over report problem-solving activities.

Assessment Strategies								Assessment Tools			
	Exams	Quiz	Paper	Oral	Prob. Sets	Port-folio	Other	Rubric	Review	Conc. Maps	Other
Small Intro	84	47	52	36	46	6	27	66	14	3	5
Medium Intro	95	58	41	19	44	3	23	68	12	2	7
Large Intro	96	59	25	12	39	2	22	63	9	4	5
Small Majors	86	37	57	43	66	5	27	66	18	4	6
Medium Majors	89	49	50	28	58	5	23	63	17	5	6

Table 7. Assessment techniques used by faculty in introductory courses and majors courses for all class sizes as percent.

	No groups %	Single Grade %	Group Grade %	Combination %	Other %
Small Intro	40	22	43	29	6
Medium Intro	53	21	42	32	6
Large Intro	56	21	53	17	9
Small Majors	39	20	46	30	4
Medium Majors	46	22	53	20	6

Table 8. Faculty assignment of individual grades for group work by class size for introductory courses and courses for majors as precent.

While a large percentage of courses ask students to solve problems, the level of independence varies with the type of course. Independent problem-solving is slightly more common in small and medium-sized courses for majors than in small to medium-sized introductory courses, and is less common in large introductory courses. Considering only small courses, courses for majors are more likely to ask students to collect and analyze their own data than are introductory courses. As might be expected, faculty in similar instructional settings more frequently ask students in courses for majors to collect data and problem solve independently. However, there is no question that many students in introductory courses are also being asked to develop and use these skills. This practice is less common in large introductory courses, although the number is sufficiently large to indicate that data collection and analysis can be done in large courses, which should prove encouraging for faculty teaching in this setting. On-line data is more extensively used at the introductory level and in larger courses. This may be an important tool for engaging students with data in ways that minimize logistical problems.

In contrast to the widespread use of problem-solving, we are struck by the small percentage of courses that ask students to pose and solve their own problems (Table 5). This seems incongruous, given the importance that scientists place on questioning and on development and testing of hypotheses. Student selection of topics is apparently rare across the disciplines with only 10% of faculty reporting use of such activities nationwide (Lindholm and others, 2002). Leaders of undergraduate research experiences have long recognized the importance of students taking ownership of the problems they are solving. It may be that there are ideas that could be adapted from undergraduate research for use in courses.

Quantitative skills appear to be important to most geoscience faculty. The extensive use of at least some quantitative problems in both introductory courses and courses for majors (Figure 7) suggest that faculty are concerned that students recognize that the geosciences are quantitative and that they learn to work with numbers as well as concepts. Quantitative skills are increasingly important in the geoscience workforce. As less than 50% of courses for majors use quantitative problems frequently, further analysis will shed important light on where these skills are developed in the curriculum.

A large proportion of courses ask students to address real-world problems of local, national, or global interest. This suggests that faculty recognize that students are motivated to learn by placing problems in a relevant context (NRC, 2000). Such problems are more commonly used in introductory courses, particularly those addressing national and global issues (Figure 6). These data suggest that faculty are much more attuned to providing context that demonstrates the relevance of geoscience in introductory courses, an observation supported by the more extensive use of role playing and debate in these courses as well. It may be that this understanding of relevance is assumed in courses for majors. Problems of local interest are only slightly more commonly used in introductory courses. This may reflect increasing interest in place-based learning where local problems and examples are used to bring concepts home to students (Smith, 2002; Woodhouse and Knapp, 2000).

We expected that students in courses for majors would be asked to read in the primary literature. However, our results also indicate that roughly 10% of all introductory courses regardless of size require reading in the primary literature for nearly every class. This suggests much more extensive use of the primary literature at this level than is generally recognized. Additional work determining the nature of these assignments and the type of primary literature referenced may show important distinctions between introductory courses and courses for majors.

Many studies have focused on the value of structured collaborations in supporting students in problem-solving (Johnson and others 1998; Macdonald and Bykerk-Kauffman, 1995). This technique is reported in 59% of introductory courses and, as might be expected, is more common in small classes (Figure 7). Structured collaborations are as common in courses for majors of all sizes as they are in small introductory

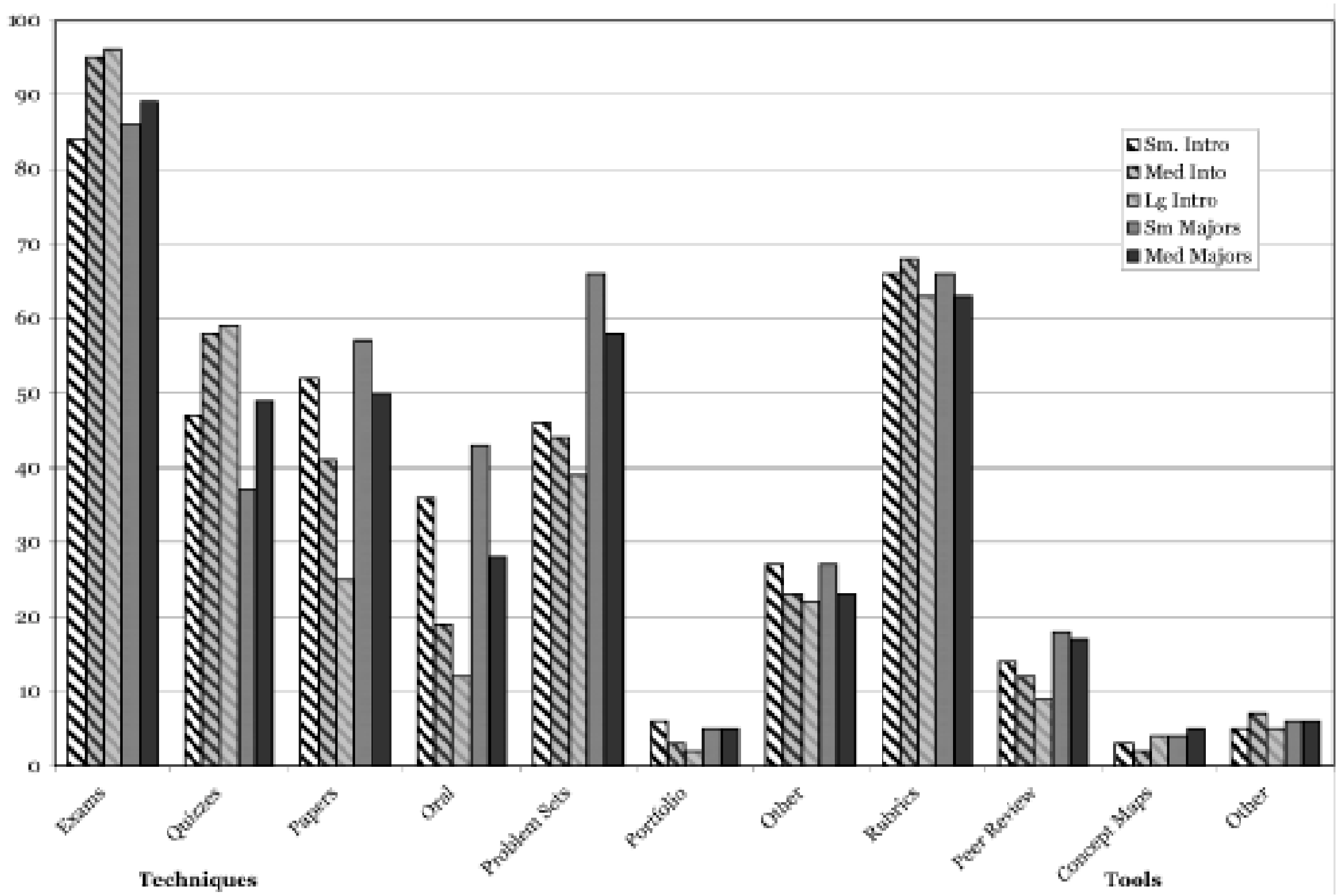

Figure 8. Assessment techniques and grading tools used by faculty in introductory courses and majors courses for all class sizes as percent.

courses. Further study could illuminate the nature of these collaborations and their relationship to independent problem-solving activities.

In sum, problem-solving activities, including those that are quantitative, are widespread in geoscience courses. In introductory courses, these problem-solving activities more frequently address national or global problems, suggesting that this context is seen as a way to motivate learning. In courses for majors, there is an increased focus on data collection if class size allows. On-line data play a particularly important role in large courses for majors. The primary literature is introduced in many introductory courses and plays an important role in courses for majors. Structured collaborations are widely used to support students in problem-solving activities.

Assessment Strategies - The results of the assessment portion of the survey appear in Tables 7 and 8 and Figure 8.

Summary - Survey results show that geoscience faculty use a wide variety of strategies to assess student learning. In addition to exams and quizzes, faculty also use problem sets, papers, oral presentations, and portfolios. The most important results are summarized below:

- Faculty give exams in the vast majority of courses surveyed.
- Quizzes are common, occurring in ~35-60% of all courses surveyed.
- Problem sets are more typical of courses for majors than of introductory courses.
- Roughly 1/2 of small to medium-sized courses require papers, as do over 1/4 of large introductory courses.
- Oral presentations are fairly common in small courses, less common in medium-sized courses, and rare in large courses.
- About 2/3 of faculty in courses of all sizes and types use grading rubrics. Other tools such as peer review and concept maps are rarely used.

Discussion - The survey results show that the assessments faculty use reflect both the class size and type (introductory or for majors). Exams are reported as an assessment tool in the largest percentage of courses of all types and sizes, indicating that exams are still the mainstay of assessment techniques.

Problem sets are the next most frequently reported assessment strategy in courses for majors. Just as problem-solving is emphasized more in courses for majors than in introductory courses, graded problem sets are a more important assessment strategy in courses for majors than introductory courses. In fact, the use of graded problems sets is so much more common in courses for majors than in introductory courses that it suggests that the type of problem-solving and the role it plays in majors courses may be substantially different than that in introductory courses. In spite of this contrast, problem sets are reported as an assessment strategy in 43% of introductory courses.

Papers and oral presentations are used more extensively in courses for majors than they are in similar size introductory courses. As courses for majors are predominantly small classes, papers and oral presentations are encountered more frequently by students in courses for majors. In contrast, quizzes are used more frequently in introductory courses than in courses for majors of similar size. Thus, even in courses of the same size, assessment of students in introductory courses rests more heavily on exams and quizzes and less heavily on problem sets, papers, and oral presentations. The one exception to this pattern is small introductory courses which have the lowest use of exams and rely more heavily on papers, oral presentations, portfolios, and other assessments than larger introductory courses. This suggests that small introductory courses may be some of the most innovative courses in the geosciences in terms of their assessments.

As one might expect, assessment strategies that are potentially more challenging to manage or time-consuming to grade are less common in large courses than in smaller courses. Oral presentations, for example, are about three times as common in small introductory courses as in large introductory courses (Figure 8). Papers are about twice as common in small courses as in large ones (Figure 8).

We are impressed by the number of courses that require papers, despite the perception that papers are time-consuming to grade. More than half of all small courses, including introductory courses, require papers, and more small introductory courses require papers (53%) than require quizzes (43%) or problem sets (46%). Even more striking is the fact that more than 25% of courses with more than 80 students require papers. These results should encourage faculty members who teach large courses that paper assignments are indeed do-able in courses other than small courses.

These results are similar to those reported nationwide for faculty across the disciplines (Lindholm and others, 2002) which indicate that exams and quizzes are heavily used. Papers and student presentations are important evaluation tools used in most classes by roughly 35% of faculty nationwide. Peer review is less common and is used by approximately 15% of faculty in most of their classes.

We are puzzled by the survey results that indicate that 2/3 of faculty members surveyed use grading rubrics. Our experience over the past several years suggests that most of the faculty who have attended our workshops have, in fact, been unfamiliar with formal grading rubrics. Respondents may have used the term "grading rubric" differently than the research team intended. This serves as a caution that terms used throughout the survey may be interpreted differently by different individuals. While we attempted to use common language, definitions of terms were not provided.

The widespread use of structured collaborations in problem-solving was noted in a previous section. One of the most challenging aspects of group work is assigning individual grades for students learning in these activities. Fifty percent of introductory courses and 60% of courses for majors are described as involving group work (Table 6). Our data show that there are a wide variety of approaches to grading this work. Approximately half of courses described assign individual grades for group work, with roughly a quarter using either a single grade for the group or a combination of individual and group grades. Strategies for assigning grades using all three approaches are described in the literature (Johnson and Johnson, 1996; Barkley and others, 2003). Our data confirm that this breadth of approaches is being explored in geoscience classrooms.

In sum, while exams and quizzes are still heavily relied upon in geoscience courses, particularly large ones, a wide range of other techniques are also in use. Problem sets are particularly important in courses for majors reflecting an emphasis on problem-solving. Papers are used in courses of all sizes and types including large introductory courses.

CONCLUSIONS

The snapshot of current teaching in the geosciences created from these data is an encouraging one and appears to reflect both our growing understanding of how students learn and a rich curriculum responding to changes in geoscience research and student needs. There is no question that research on learning and resulting recommendations for best classroom practice that have emerged over the past decade have had an impact on geosciences classes. Our survey shows widespread use of interactive lecture techniques, problem-solving activities, and assessment strategies that challenge students to demonstrate higher order thinking. Extensive topical courses, interdisciplinary offerings, and use of problems of local and global interest, particularly at the introductory level, may reflect both a desire to make geoscience more relevant to students and an increasing awareness of the Earth as a system.

The survey data contain substantial evidence that faculty in all settings are implementing creative solutions to engaging their students in learning, problem-solving, and higher level thinking. We did not anticipate that papers would be as widely-employed in introductory courses as appears to be the case, and their use in large introductory courses is particularly notable. Similarly, the use of problem-solving, including activities that address problems of local, national, and global interest, suggests that faculty understand that students are motivated to learn by real world problems. We are particularly impressed that faculty engage students, including those in introductory courses, with the primary literature and in interpretation of data to address these problems. Our survey confirms the enthusiasm for teaching with data and for complex real-world problems reported by a smaller group of faculty in workshops on this topic (Manduca and Mogk, 2002). Last, while the numbers are relatively small, a significant percentage of faculty are experimenting with student-centered techniques such as role-playing, classroom debate, portfolio assessment, and peer review.

Most faculty appear to be engaged in trying techniques beyond lecture to engage students in learning, and faculty appear to be willing to experiment and open to trying new approaches. On the other hand, there is room for growth. Our data suggest that most faculty are still using these techniques infrequently. These results strongly support the continued offering of professional development activities that both bring new ideas to faculty and address the practicalities of widespread implementation of these techniques.

Looking to the future, the study raises as many questions as it answers. Additional work is needed to understand how faculty are using various techniques in different classroom settings, along with the impact of these techniques on learning. In particular, studies of problem-solving in both introductory courses and courses for majors could provide much additional information about a learning experience that our data indicate is widespread and commonly encountered by students at all levels.

These data form a baseline against which we can measure changes in the future. Today, we can only compare current practice to recommendations of the past decade. In the future, we will be able to compare to our baseline data to answer questions such as: How did geoscience courses change as result of a new generation of students who have different experiences that reflect the on-going reforms in K-12 education? How did faculty adapt their classroom strategies as new technology makes different kinds of activities and understandings possible? How did faculty continue to change in response to new insights from research on learning, particularly as that research focuses more directly on geoscience learning? As researchers learn more about the role of motivation in learning, how did faculty adapt their teaching to increase student interest and motivation?

The survey results suggest that geoscience faculty are ready to meet this future. While faculty still rely heavily on lecture and tests, the data show that most faculty have a range of teaching strategies. We suggest that this reflects a level of understanding that skill/drill and lecturing have limitations in terms of student learning, and that active engagement of students in is important--both for student learning of content, and to improve student attitudes toward both science and learning. Our experiences with faculty indicate that most are extremely interested in their teaching, most recognize when their teaching leads to learning, and most know when their students are not engaged in a course. We hypothesize that, in this climate, availability of resources to assist faculty in improving their teaching could have a major impact in the future, as could structural changes in academia designed to promote more attention to, and recognition for, effective and innovative teaching.

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