Geoscience Education: Building a Research Paradigm*

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Prepared for: "Bringing Research on Learning to the Geosciences", July 8-10, 2002, Racine, Wisconsin

* Some excerpts and ideas borrowed from Research Methodologies in Science Education, column prepared for the Journal of Geoscience Education (May 2001 through present), co-authored by J. Kurdziel and J. Libarkin.

Synopsis. Science education is currently undergoing a transformation, especially at the collegiate level. Teaching reforms are being implemented across the board by faculty, departments, and institutional policy committees interested in improving upon the scientific literacy of the voting public. With this transformation, education research within scientific disciplines is finding new respect, and more and more science faculty are devoting themselves to studying the classroom environment. Traditionally, however, scientific and education disciplines have remained unconnected, with limited transfer of information and new knowledge between the two fields. As a result, disciplinary-specific science education research is often far removed from research paradigms that have long been established in the behavioral sciences. Similarly, the field of science education, while grounded in established methodologies, rarely has a direct impact on the teaching and learning actually occurring in classrooms. Indeed, this disparity exists in our disciplinary journals; researchers writing for the Journal of Research in Science Teaching rarely engage in science classroom instruction themselves, especially at the college level, and studies presented in the Journal of Geoscience Education are often presented by teaching faculty, although with little focus on the suitability of research design. Geoscience education today is primarily embedded in classroom, or localized, research, and it is to methodology and structure that researchers must now turn their attention. To ensure that research findings are useful and applicable outside of the immediately studied environment, the geoscience community must come to a consensus about the form education research should take, the methods for acquiring and analyzing data, and the means for establishing research validity. With this consensus, education researchers can ultimately implement a common research paradigm that will open the lines of communication across all disciplines.

Geoscience education has been an active focus of research within the education community for at least fifty years, as evidenced by the long publication record of a journal specifically designed to document and promote geoscience education. The Journal of Geoscience Education (previously known as the Journal of Geological Education) has provided a venue for the presentation of innovative ideas in instruction and research findings since 1951. In the ensuing half a century, interest in geoscience education has fluctuated, although the past decade has seen a resurgence in policy interest and funding for educational initiatives, especially at a national level. Faculty are now being asked to focus on the successes, and failures, of their teaching endeavors.

Faculty expectations for student learning usually cover a wide range of possibilities. In general, a number of student outcomes can result from engagement in a course, including content knowledge acquisition, skills development, changes in attitudes/values/beliefs, and long-term behavioral outcomes (Ewell, 1987). At the introductory and non-major levels, goals for geosciences courses can vary widely, although they typically include several of the following: deep conceptual understanding of fundamental principles, improved understanding of the processes of science, improved attitudes toward science, and skills development (critical thinking, synthesis, and communication). Apart from attitudinal shifts, many faculty would agree that beginning geosciences courses should provide students with the knowledge and skills necessary for complex decision-making about their own interactions with the Earth. Upper division courses are usually focused on learning the "language" of geology, acquiring the higher order thinking skills necessary for interpreting geologic data, and developing skills for evaluating the scientific literature. What needs to be done to further our understanding of how students learn in the geosciences? What techniques are most effective at facilitating learning and do additional factors influence learning? What protocols should be established to ensure valid and reliable research endeavors in the future? *Ultimately, how do we know if students have learned?*

University professors typically have many theories about the most effective methods for promoting student learning. Some faculty swear by traditional lecture, while others insist that alternative techniques must be used if students are going to become scientifically literate. Phrases like "minds-on, hands-on", "inquiry", "collaborative and cooperative learning", "instructional technology", "problem solving instruction", and "peer-peer interactions" are being used increasingly by university faculty to describe their latest innovations in the classroom. The number of education sessions at annual geology and geophysics meetings is increasing, resulting in wide dissemination of a variety of teaching techniques, curricula, technologies, and course structures. In fact, professional geoscience organizations are actively sponsoring workshops advancing these reforms. For instance, Geological Society of America and American Geophysical Union have both sponsored workshops on collaborative learning strategies, technology, and/or inquiry-based instruction in recent years. Although these alternative methodologies are adopted from studies that have shown their effectiveness at the K-12 level (e.g., Johnson and Johnson, 1994) or in other disciplines (e.g., Zietsman and Hewson, 1986), relatively little research has addressed the effectiveness of these techniques for college-level education, and very few studies have focused on geoscience education at any grade level. Those studies that do consider geoscience education are primarily grounded in classroom, rather than educational, research (Angelo and Cross, 1993).

A survey of the articles contained within the Journal of Geoscience Education exemplifies the predominance of classroom research in geoscience education. Classroom research refers to practices that assist a teacher in determining student learning gains and instructional effects.

Student grades, exams, in-class writing assignments, and even focus groups all provide some insight into course outcomes. Teachers can use classroom assessment to inform their own instruction, but are usually not able to generalize their findings to other classrooms or educational settings. Educational assessment uses similar data types; however, the validity and reliability of the research design must also be established. For example, classroom exams are usually created by instructors based on their individual beliefs about what students should have learned and how questions should be asked. Outside opinion is rarely consulted, and qualitative and/or quantitative methods for validation are never required to prove that an exam score is a reliable measure of student learning. The development of a test for educational assessment, however, does require strict adherence to validity and reliability guidelines. This added effort helps ensure that educational research findings can be generalized to multiple educational environments.

The Journal of Geoscience Education issues from 1991-2001 contain 610 articles. Most of these articles persuasively describe a course, curriculum, program, or useful classroom technique, with about 30% of the articles explicitly mentioning the effectiveness of the educational initiative (Fig. 2a). Although many of the studies presented in this journal describe innovative and potentially effective teaching methods, it is difficult to determine the extent of student outcomes using only classroom assessment methodologies. In fact, many authors acknowledge this difficulty, stating about their own research:

> *This new approach seems more successful, although it is difficult to evaluate...*[1]
> *How can we evaluate the success or failure of a course such as this one?* [2]
> *It has not been feasible to demonstrate statistically the effect (if any) of...* [3]

In all only 19 articles use a quantitative instrument or established qualitative techniques, with just eight studies using a previously published (4 articles) or partially-normed (4 articles) assessment tool (Fig. 2). We as a community must encourage geoscience education researchers to move beyond classroom research and begin to adopt methodologies that have long been used to study human interactions in the fields of education, psychology, and nursing. This adaptation of research methodologies will help ensure that future studies will be applicable to a wide range of learning environments.

Personal Perspective. I would argue that a discussion of learning in the geosciences will have only modest impact on the geoscience education community at large until we address the twin issues of validity and reliability in research. Geoscientists actively engaged in education research have by and large focused on classroom research and overlooked existing paradigms for educational research methodologies. Although classroom research is actively pursued by many geoscience educators to inform their own classroom instruction, few of these studies have evolved into educational research that can be used to inform the community at large. In particular, a variety of methodologies are currently being used to acquire, analyze, interpret, and report data. Without a consensus within the community as to what does and does not constitute a valid and reliable research paradigm, research into learning in the geosciences can never evolve beyond classroom specific conclusions. In particular, we as educators should be concerned with the generalizability of our research findings to all classrooms and learning environments.

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[1] Wiswall and Srogi, 1995; [2] Picard, 1993; [3] Lutz and Srogi, 2000

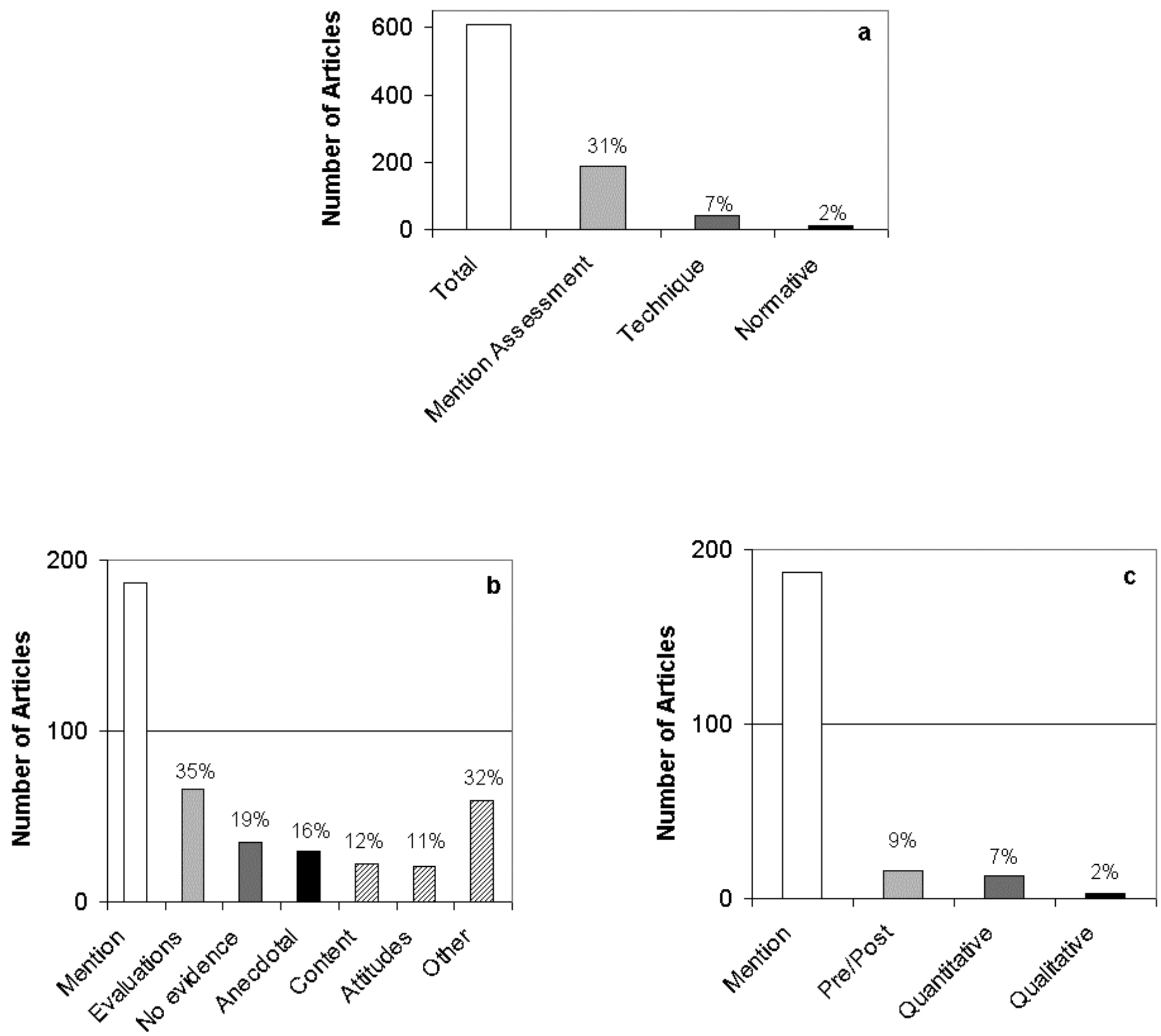

Figure 1. Review of Assessment Practice, Journal of Geoscience Education, 1991-March 2001. Percentages are with reference to total number of articles (**a**) and those articles which explicitly mention assessment or effectiveness (**b**, **c**). **a.** 610 articles appear, with 187 referring to assessment or effectiveness in some form. Of these, only 10% use established educational research methods and only 2% (11 articles) use some type of normative measure that would allow comparison with other studies. **b.** 35% of the studies provide no evidence to support claims of effectiveness, or use anecdotal evidence only. Remaining studies rely overwhelmingly upon course or activity evaluations, and/or one or more of the following: content knowledge, attitudes, faculty-generated survey instruments, grades, participant self-assessments, interviews, focus groups, attendance rates, and student work. **c.** Of the 187 studies that mention assessment, only 10% utilize pre/ post-testing methods and/or quantitative statistical techniques. Only three studies make use of established qualitative or quasi-qualitative methods.

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