Research Methodologies in Science Education:
The Qualitative-Quantitative Debate

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In our November column (Libarkin and Kurdziel, 2001) we discuss various types of qualitative data, how these data can be collected, and a variety of methods for analysis and use in classroom assessment. However, we only touch upon the notion of appropriateness; that is, when is it appropriate to use qualitative techniques, and when are quantitative techniques more suitable to a study? This issue is a long-debated and much discussed topic in educational research, and is commonly called the Qualitative-Quantitative Debate.

Most researchers would agree that data, even from the most controlled experimental study, are never purely quantitative. The context of the study and the perspective of the researcher always affect the way data are collected and interpreted. Where then does the division between qualitative and quantitative lie? Qualitative research focuses on the context of a phenomenon, while quantitative research seeks to develop phenomenological generalizations that can be applied to a range of contexts. Eisner (1991) discusses a continuum of data types ranging in quality from fictional to structured. In this framework, purely qualitative data sit near the fictional end of the spectrum and are directly related to the individual or setting under study, while quantitative data are highly controlled. For issues of science education assessment, data can be classified similarly as a spectrum ranging from anecdotal to statistical (Figure 1). Qualitative data stemming from classroom observations, interviews, or written documents can be shifted into the realm of quantitative data through content analysis (Libarkin and Kurdziel, 2001). Similarly, quantitative data in educational settings are collected with subjective tools, such as Likert-scales. Data are further quantified through statistical analysis. Some researchers would argue that no data are purely quantitative, especially since the interpretation of statistical analyses is often subjective (Lincoln and Guba, 1985; Creswell, 1994).

Although this continuum between qualitative and quantitative research exists, the assumptions inherent to each type of study are dramatically different (Trochim, 2001). Quantitative researchers study social interactions just as they would study natural phenomena. In a quantitative world, everything can be reduced to a theoretical framework that describes the social context. Thus, the quantitative researcher treats social phenomena as a set of interconnected variables, and every social phenomenon is the result of interactions between these variables. On the other side of the debate, qualitative researchers reject the idea that the social and natural world can be studied in similar ways. Instead, qualitative researchers believe that human behavior is always a function of the setting in which behavior is being observed, and that different individuals may act differently in identical settings. Qualitative researchers do not deconstruct social interactions into composite variables. Indeed, the most strident qualitative researchers would argue that generalizations can never be made; each setting is unique from every other.

QUALITATIVE RESEARCH: PROS AND CONS

Qualitative research is an unconstrained approach to studying phenomena. Although a number of standard approaches to collecting and interpreting qualitative data exist (Bogdan and Biklen, 1992), qualitative research is strongly dependent upon the researcher conducting the study. The researcher decides upon the type of data gathered and the methods used to analyze those data. Herein lies the power and the weakness of qualitative research. Qualitative data is typically rich in details and context, interpretations are tied directly to the data source, and research validity and reliability are based upon the logic of the study interpretations, rather than statistical tests (Table 1). Qualitative studies, therefore, provide a window into a contextual setting, and a logical picture of events within that setting. However, the attention to detail central to qualitative analysis also means that study conclusions will typically only apply to a very narrow range of circumstances. Additionally, the training and beliefs of the qualitative researcher may themselves shape the research structure and findings. As a result, qualitative findings may not provide any correlation between cause and effect on a broad scale.

QUANTITATIVE RESEARCH: PROS AND CONS

Quantitative research focuses on a set of narrowly defined research methodologies. The tools and techniques used for gathering and analyzing data are well established, and the validity and reliability of a study typically depend upon following pre-existing

Characteristic	Qualitative		Quantitative	
	Pros	Cons	Pros	Cons
Methodology	Issues can be studied in great detail. Analytical approach is unconstrained.	Results may be applicable to only a narrow range of individuals or settings. Often no connection to causes.	Results from a variety of individuals or settings can be used to develop a single explanatory model.	Analytical approach is constrained by established standardized methods. Individuals may be artificially forced into categories.
Interpretation	Interpretation is often based on manipulation of raw data and is therefore tied directly to the data source.	Individual beliefs of the researcher may shape the data interpretation.	Statistical analysis, although not perfectly free of subjectivity, is typically independent of the researcher's personal belief system.	By the time a quantitative study reaches the interpretation stage, the context in which the data was collected may be lost.
Validity/Reliability	Validity and reliability are established through logical reasoning and consensus; statistics not required.	Researcher acts as the instrument; training and skill of practitioner can bias results.	Validity and reliability are highly controlled variables established statistically; limited training required.	Establishing validity and reliability is time consuming.

Table 1. Comparison of some aspects of qualitative and quantitative research.

methodologies (Table 1). The wide range of available statistical methods (Creswell, 1994) allows researchers to develop explanatory models that can account for phenomena occurring in similar settings. These models allow for the development of theories of cause and effect, and can have significant predictive power in classroom settings. Additionally, because data analysis is governed by statistics, the personal beliefs of the researcher will have only minimal impact on study findings. However, this modeling approach can result in an artificial categorization of phenomena that has little correlation with the real world. That is, unlike qualitative research, the context in which data was originally collected may be lost beneath the layers of statistical analysis inherent to quantitative research.

ASSESSMENT OBJECTIVES

Choosing one type of data over another ultimately hinges on the objectives of your assessment efforts. The arguments for and against the use of each research paradigm suggest a number of questions that can be used to determine which methodology will be most useful for a particular study. Researchers tend to categorize these questions depending upon their own research perspective. The following questions can be found in a variety of forms in Trochim (2001), Lincoln and Guba (1985), Bogdan and Biklen (1992), and Miles and Huberman (1994).

I. Generating versus Testing Theories: Do I understand the phenomenon under study well enough to develop a theory about the interactions between variables, or do I need to explore the setting further?

Both quantitative and qualitative methods are concerned with exploring phenomena. However, qualitative analysis is primarily concerned with gaining direct experience with a setting, while quantitative analysis seeks to document occurrences passively. Because qualitative research is an inherently exploratory endeavor, the potential for generating new theories and ideas is significant. Quantitative data, on the other hand, are most valuable when hypotheses and theories have already been established and are being evaluated.

II. Single versus Multiple Variables: Are the variables that could potentially affect student outcomes already identified, or is the goal of your project to document factors influencing student outcomes?

Qualitative studies can be thought of as univariate, where the single variable is the context under observation. In fact, a goal of qualitative research may be

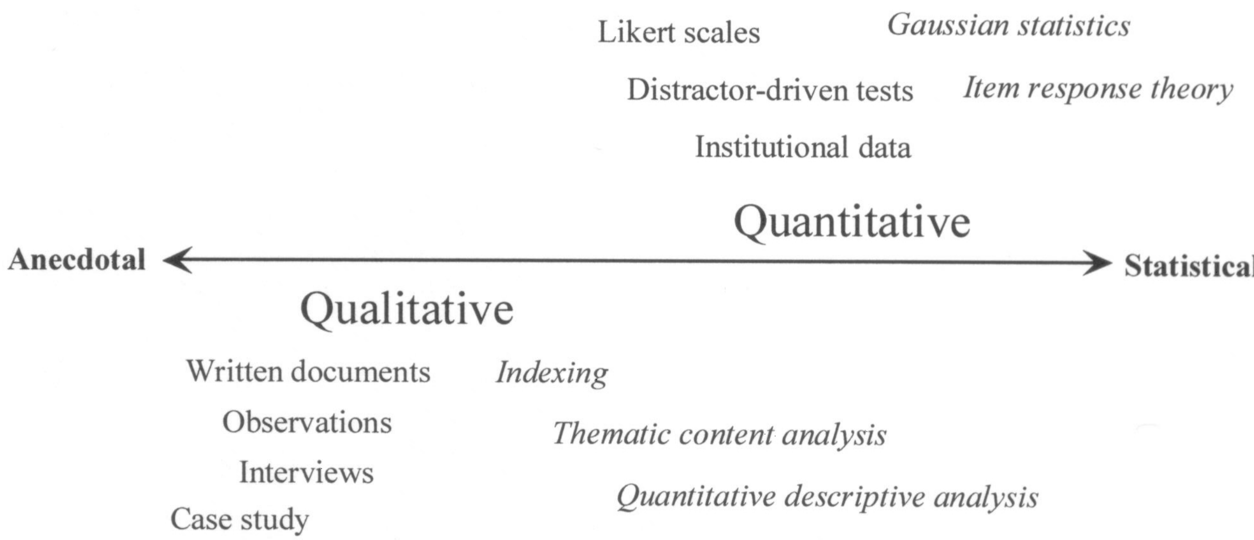


Figure 1. Continuum of some data (plain text) and methodology (italics) types, from anecdotal to statistical. Qualitative data can be analyzed using a number of methods (Libarkin and Kurdziel, 2001); these methods bring qualitative data into the quantitative realm. Similarly, quantitative analytical techniques are used to shift raw data into the realm of statistics.

the identification of variables affecting the phenomenon under study (Creswell, 1994). For instance, in a study of urban mothers, Barton and others (2001) used group interviews, observations, and surveys to identify both perceptions about science and the factors that appeared to influence these viewpoints. Once key variables have been identified, quantitative methodologies can be used to explore the relationship between variables and broader ramifications.

III. Detail versus Generalization: How much detail is necessary to meet the study objectives? Is generalization to other settings an objective of the study? Is the study population large enough to allow for generalization to other populations?

Qualitative studies seek to recreate the contextual setting as a framework that can be analyzed and understood. By necessity, qualitative research often consists of as much data as possible, including detailed field notes, tape and video transcripts, and written documents. This abundance of data allows researchers to explore a single setting in great detail, for the purpose of understanding the dynamic relationships within that setting. As a result, effective qualitative research allows outsiders to view a situation from the perspective of the individuals involved. However, support for external validity, the ability to transfer conclusions to other research settings, can be difficult to maintain in purely qualitative studies. This limits the impact of the study for other researchers. Quantitative research, on the other hand, typically focuses on overarching "truths" that are applicable to a range of similar settings and populations. The uniqueness of individual contexts is generally not revealed by quantitative research.

MIXED METHODOLOGY RESEARCH

A research plan can incorporate both qualitative and quantitative data (Fig. 2). Although not always possible to blend the two paradigms, qualitative analysis provides the context lacking in quantitative research, and quantitative analyses broaden the implications of a purely qualitative study. Additionally, the use of multiple data sets can inform the research, yielding insight and methodological changes that improve the study and strengthen findings. Although some researchers choose one research paradigm over the other, the combination of statistical analysis with contextual data has been used with great success by a number of researchers. Most importantly, these dual studies are able to inform educational practice for both the local setting under study and the broader context. For example, Derry et al. (2000) used both types of

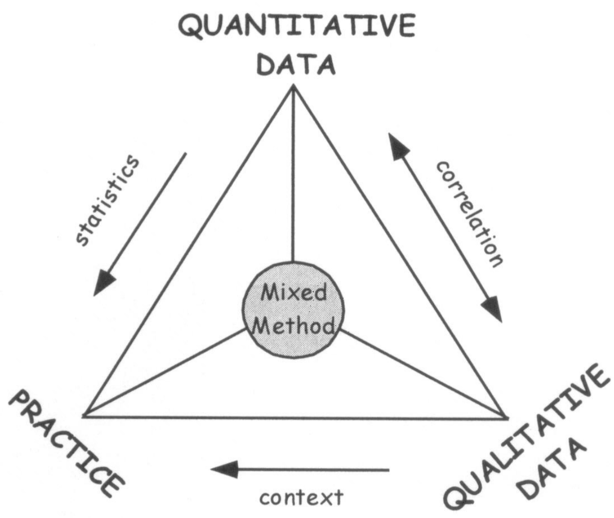


Figure 2. Relationship between qualitative data, quantitative data, and practice. Qualitative and quantitative data both inform practice, the former with contextual frameworks and the latter through statistical analysis. Both types of data can be correlated within a single study, and in actuality neither data type can exist in isolation. A mixed method study would sit between the interface of the quantitative/ qualitative realm and would inform actual practice.

analysis to explore the impact of a non-traditional math course on students' reasoning ability. The quantitative evaluation showed statistically significant changes in student ability after completing the course. However, quantitative data alone cannot reveal why reasoning ability improved, nor if the course was responsible for the change. The juxtaposition of qualitative data revealed a relationship between course design and both positive and negative effects. This clarification of the educational effect of the course lends credence to the study's conclusions and bolsters the argument for generalization of these findings to other courses and student populations. Other mixed methodological studies worth exploring include an analysis of technology in elementary classrooms (Russek and Weinberg, 1993), a proposed study of sports fans (Jones, 1997), and an analysis of videos of classroom teaching (Jacobs et al., 1999).

AN EXAMPLE STUDY

Erik, a 15-year veteran professor, has designed a new series of introductory geology labs. He has chosen to incorporate inquiry methods into these labs, replacing the more traditional expository methods of previous years. Erik wants to find out if these labs are effective at improving student content knowledge, suggesting a quantitative research approach. He decides to try a mixed methodology, using both qualitative and quantitative methods to answer his research question. Erik is unable to find an existing content test, so he puts together a 20-question test using tried-and-true questions from old final exams. Erik plans to give this test to his students at the beginning and end of the semester, and use statistical analyses to compare the pre- and post-test scores. Erik also hires an education graduate student to observe his laboratories and conduct focus groups with his students.

Before the start of the semester, Erik considers the questions he will be able to answer with his study. Although he taught more traditional "cookbook" labs in previous years, he realizes that he has no way of comparing the new labs with the old. As a result, he won't be able to make any conclusions about the relative effectiveness of inquiry versus expository laboratory methods. However, Erik will be able to determine if his new labs are having a positive effect on student understanding of fundamental geology concepts. Because Erik is also collecting qualitative data, he will be able to both explain anomalies in the quantitative data and reveal unexpected outcomes not covered in the pre-post assessment.

Erik was able to collect pre- and post-test data from 30 students in each lab section. He also has observations conducted four times during the semester and an end-of-semester focus group from each lab section. Before conducting any analyses of the test data, Erik first determines that the pre-test data are Gaussian in distribution (Fig. 3). Additionally, the pre-test data for labs A and B are very similar, with means of 52.3 and 53.5, respectively (Fig. 3). Now Erik is ready to compare the pre-course and post-course data for each lab section. Surprisingly, Erik finds different quantitative effects in the two labs. In lab A, students experienced a significant increase ($t = 2.3$, $df = 58$, $p = 0.05$) in their test scores (Fig. 4). In lab B, however, student test scores appear to increase and decrease only slightly, and at random. Although Erik is happy that his lab seems effective at increasing geology content knowledge for his Lab A students, Erik is unsure how to account for the differences between the two lab sections.

Analysis of the observation and focus group data suggests several potential causes of the discrepancies between the results from the two lab sections. Analysis of the observations (Appendix A) suggests that students in Lab B were less focused than those in Lab A, with significantly more non-course related discussion occurring in Lab B. Additionally, excerpts from the two focus group reports state:

Focus Group (Lab A): 15 students attending. Three-quarters of the students had attended an optional

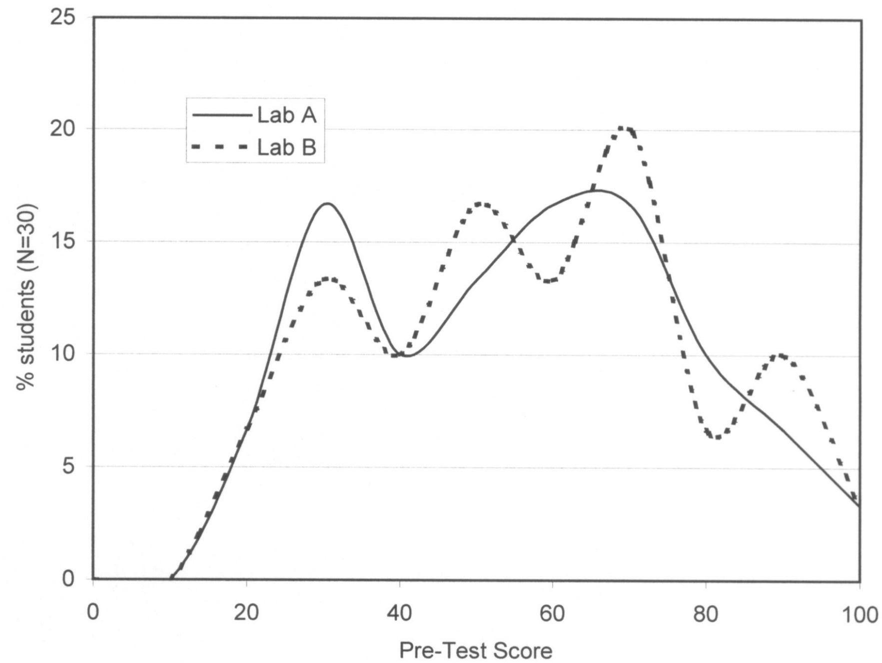


Figure 3. Histogram of student pre-test scores in lab sections A and B. Notice that the scores from each section are similar and the distributions are Gaussian. Lab A pre-test mean = 52.3; Lab B pre-test mean = 53.5.

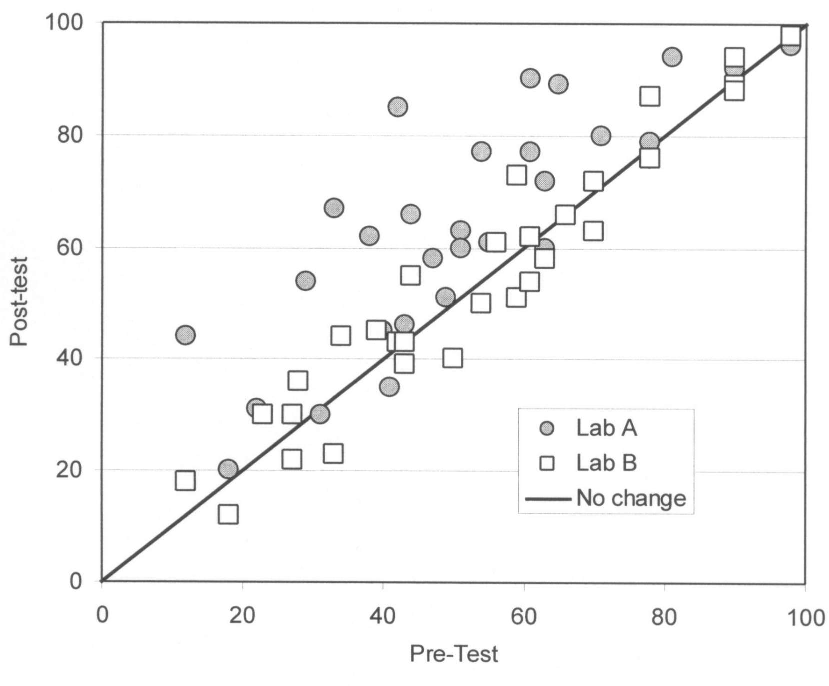


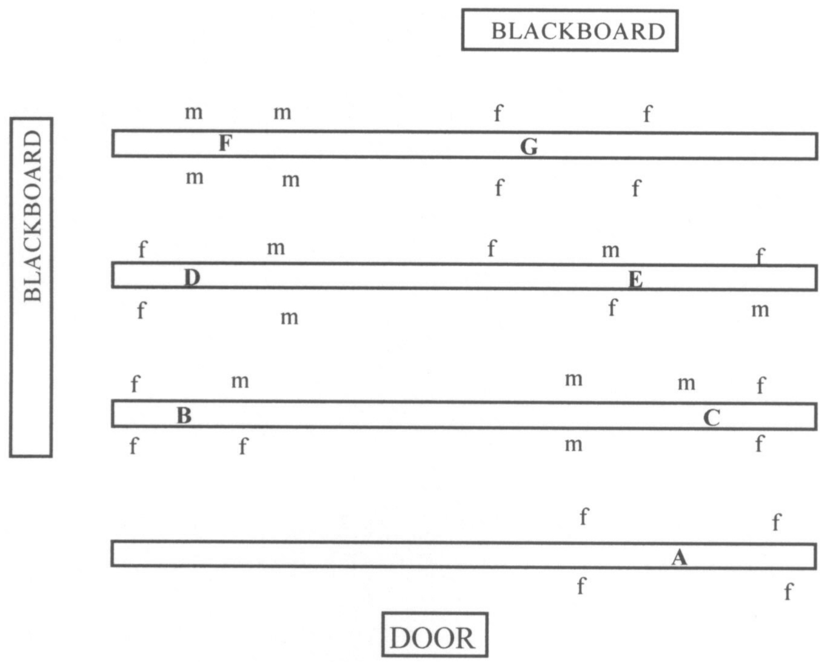
Figure 4. Pre- versus Post-test scores for lab sections A and B. Lab A: pre-test mean = 52.3, post-test mean = 64.4. Lab B: pre-test mean = 53.5, post-test mean = 54.1.

Appendix A. Selected notes from observation of Labs A and B.

Observation A2, Observer = JK

Total # of students: 30 Approximate ages of students: 18-21; # of female: 14; # of male: 16

Diagram of Classroom:



25 students seated by 8:00, 5 students late

8:03 begin

Prof.: "What is rate…if we fit a line to that data"

Female (A): "The slope"

Prof. draws a straight line thru data…

Prof.: "How do we get slope? Anybody?"

Male (B) "Look at change in Y over change in X."

Male (C): "y = mx+b…that's the slope…I'm just trying to help"

8:07 Males (E) looking at graphing instructions in labbook

Female (C): "Why are you so awake this morning!"

Female (C): "I get .4 let me go ask him if that looks right."

Male (F): "This is the same data…it can't be the same right"

Male (F): "It's the same as is"

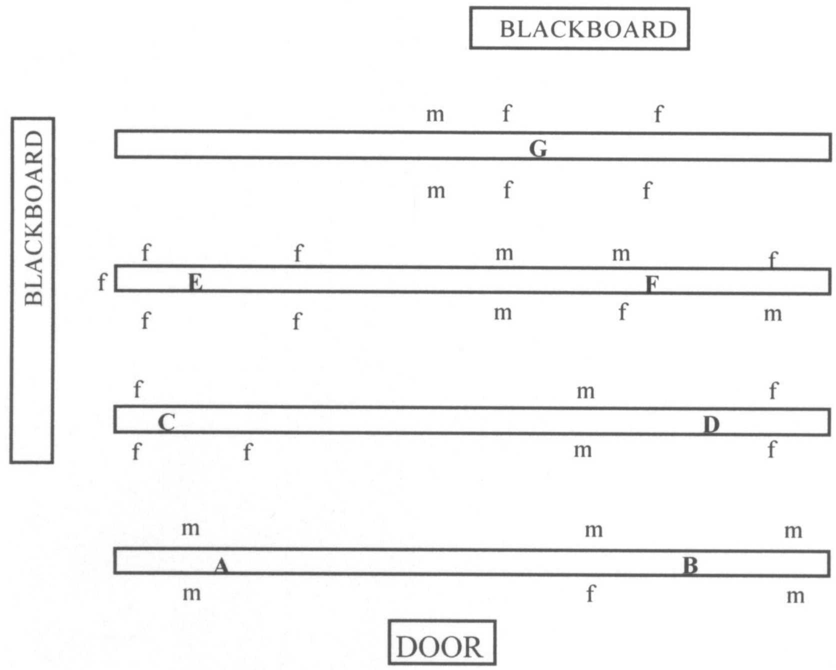
Female (C) raise her hand...

Appendix A. Selected notes from observation of Labs A and B.

Observation B2, Observer = JK

Total # of students: 30 Approximate ages of students: 18-30; # of female: 17; # of male: 13

Diagram of Classroom:



20 students seated by 11:00, 10 students late

11:00 a.m.

Prof.: "Get your lab report ready, make sure your name is on it and hand it down"

11:05 Female Late

Prof.: "The lab today is pretty involved so we need to get working on it."

Female (A): "It gave me chills and hives all…"

Prof.: "We need to start today by talking about graphing... (Begins explaining line graphs)

11:06 2 females late

Prof.: "If you don't have graph paper with you, I have some here…"

Male (B) to male: "Do you speak spanish?"

11:08 Loud conv. at tables A and G for two minutes, while Prof lectures

Prof. (to whole lab): "Please pay attention to me"

Male (A) to male: "So if you take this number you can get the slope of the line."

Male (F) to female: "I think all girls are like that…"

11: 11 Female(G) chatting to whole table about party the previous night...

Appendix A. Continued.

help session at least once. Overall, students felt that the pre-lab introductions were a great way to get prepared for actually working on the lab. Two students felt the pre-lab instructions took too long.

Focus Group (Lab B): 13 students attending. Several students indicated that other students would hold conversations during the lab that were distracting. Even though the professor would ask these students to be quiet, conversations would often start up again. Three-quarters of the students had never attended an optional help session offered by the professor. Overall, students felt that the lab meetings were boring and might be more exciting if they spent more time working on the lab and less time listening to the professor. Three students thought the pre-lab instructions were helpful.

These qualitative data suggests three possibilities:

1. Several students in Lab B routinely talked and disrupted the other students in Lab B. This may have affected the ability of students to learn the material.

2. 75% of Lab A students attended special help sessions; only 25% of Lab B students attended. The help sessions may be a necessary component for learning the material.

3. Lab B students were generally less enthusiastic about the lab. This lack of enthusiasm may have prevented students from learning the material.

Without further study, Erik is unable to determine the exact cause of the different outcomes between the two lab sections. Indeed, Erik is now faced with three entirely new questions: Does the behavior of a few students affect the learning of everyone in a class?; How much impact do after class help sessions have on increasing student content knowledge?; and Does attitude affect learning?. With further study in future semesters, Erik should be able to discover the relative importance of different course components, and ultimately answer his original question about the impact of inquiry labs on student learning. Additionally, Erik can use the observations and focus groups to modify his instruction. Primarily, Erik plans to pay closer attention to potential classroom distractions, such as off-topic conversations. Additionally, Erik has decided to break the pre-lab lecture into five-minute pieces that he will distribute throughout the three hour lab meeting.

CONCLUSION

The power of qualitative research rests on the open-ended nature of qualitative inquiry (Jacobs et al., 1999). The generation of new ideas opens a path to further research, while the detailed presentation of the participants' views facilitates communication of qualitative findings to other researchers. Although cause and effect may not be determined by a qualitative study, qualitative findings often set the foundation for future quantitative approaches. In contrast, the power of quantitative research lies in the researchers ability to summarize research findings in statistically meaningful ways. Given large enough data sets, findings can also be generalized to other populations. Both qualitative and quantitative methods can be powerful tools for understanding the relationship between teaching and learning. Each methodology provides a unique perspective that can be important for unraveling cause and effect. Researchers should pay particular attention to the construction of research questions before gathering data, and choose the methodology, or combination of methodologies, that is most likely to provide meaningful answers.

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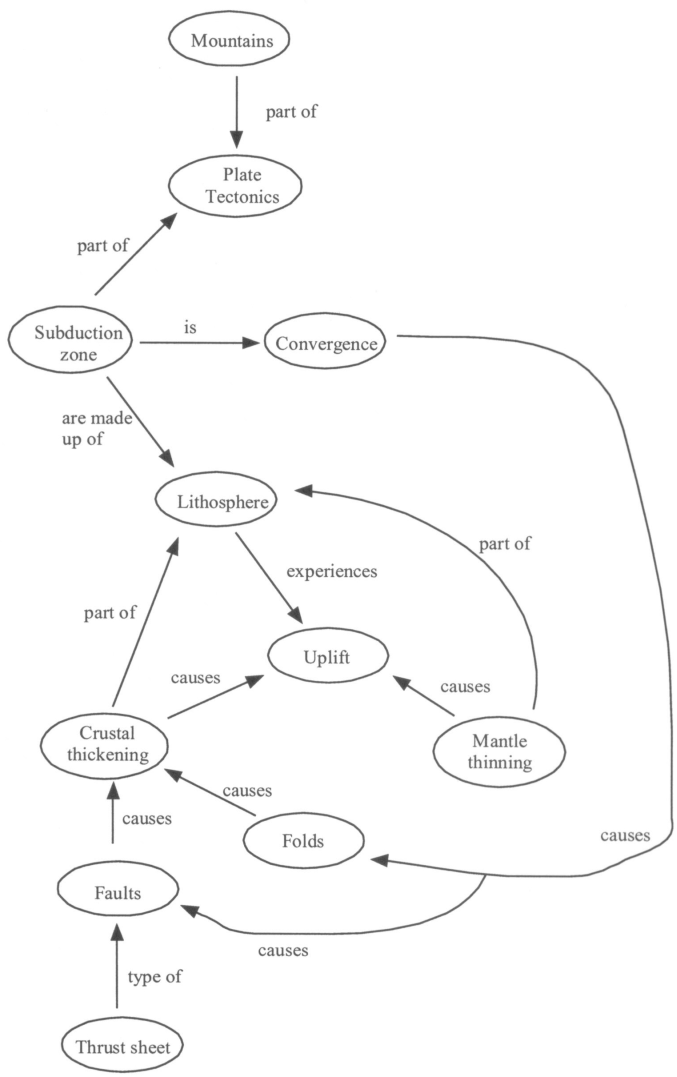

Figure 3. Concept map of mountain building.

Correction to September 2001 column, Research Methodologies in Science Education: Assessing Students' Alternative Conceptions. Authorship of that column should also have read Kurdziel and Libarkin.

EDUCATION AND OUTREACH DIRECTOR
The Geological Society of America

POSITION ANNOUNCEMENT

The Geological Society of America (GSA) seeks an Education and Outreach Director to lead the Society's efforts to promote excellent geoscience education, in its broadest sense, to students, educators, GSA members, the public, the media, and public policy makers. GSA is a scientific society serving 16,000 members worldwide and is headquartered in Boulder, Colorado.

The Director will ensure that efforts in GSA Education and Outreach have a national impact on the visibility of geosciences and the excellence of geoscience programs at all educational levels. The Education and Outreach Director will be expected to develop and manage programs in support of GSA's goal of promoting geoscience in the service of society. It is expected that new programs will be self supporting through appropriate grants or other outside resources. The Director will work with GSA Council and staff, as well as with the GSA Education Committee, the National Association of Geoscience Teachers, and with members, associated societies, and other organizations to ensure coordination so that GSA Education and Outreach programs and efforts are an integrated part of a national strategy to raise the level of geoscience awareness and visibility and to improve the quality of education in the geosciences at all levels.

Candidates for this position should hold an advanced degree in geoscience, a related discipline, or science education and should have a record of scholarly and professional accomplishments in geoscience education. We are particularly interested in candidates who have, in addition, demonstrated interest and achievement in promotion of geoscience awareness with policy makers, or through the media. Leading candidates will be able to demonstrate, through recent achievements, that their contributions have effected durable and fundamental change in at least one of these areas. Preferred candidates will also have experience in strategic and financial planning, program development and implementation, budget management, and documented success in team leadership and membership. The successful candidate will be committed to applying his or her professional energy in serving the overall mission of GSA.

The Education and Outreach Director will report to the GSA Executive Director. Salary will be commensurate with experience, and includes a highly competitive benefits package, including matching contributions to a 403(b) after 6 months of employment. GSA is an equal opportunity employer and ADA compliant. The anticipated start date for this position is August 2002.

Applicants should send their curriculum vitae, a statement of interest and qualifications, one or more reprints or other samples of professional writing relevant to the described position, and the names and contact information of three professional references to the address below. Review of applications will begin March 1, 2002, and will continue until the position is filled.

Chair, Education and Outreach Director Search Committee
c/o Dr. Jack Hess, Executive Director
The Geological Society of America
PO Box 9140
Boulder, Colorado 80301

National Association of Geoscience Teachers

Job Position

Executive Director

The National Association of Geoscience Teachers seeks applications for the position of Executive Director. We seek an individual with a demonstrated commitment to and knowledge of the issues in K-16 geoscience education. The successful candidate will be a person with excellent organizational and interpersonal skills as well as the ability to communicate effectively with a range of constituencies in the Geoscience community. The executive director's primary responsibilities will include:

- Representing the views of NAGT to other geoscience societies, governmental agencies, and the public.
- Coordinating and facilitating NAGT activities and programs mandated by the Executive Committee and/or its sub-committees.
- Maintaining all financial and legal documentation required for a non-profit organization.
- Acting as advisor and resource person for long-term implementation of Association policies and practices.
- Managing the Association's office including membership databases, elections, operating budget and endowment funds, archival activities, and logistics for semi-annual meetings. The Executive Director will be responsible for the hiring and supervision of any administrative assistants. Funding is available for administrative support and travel.

A full description of the responsibilities of the Executive Director can be found at www.nagt.org.

Those interested in applying should send a vita, statement of interest and experience, and the names of three references to:

Dr. Jeff Niemitz
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Phone: 717-245-1285
Fax: 717-245-1971

Deadline for application is March 15, 2002