

Qualitative Methodologies in Chemical Education Research

Challenging Comfortable Paradigms

Amy J. Phelps

University of Northern Iowa, Cedar Falls, Iowa 50613

This paper will describe chemical education research that is conducted in classrooms using a qualitative methodology. In this type of research, the classroom becomes a laboratory in which the researcher studies interactions between the learners, the teacher or teachers leading the instruction, and the material being studied in hopes of better understanding the intersections where learning occurs.

When one uses the chemistry classroom as a research laboratory, the type of methodology that is implemented must be different from the research we, as chemists, were trained to do. The classroom is a complex environment with a multitude of variables few of which are within the control of the researcher. Qualitative or naturalistic research provides an established methodology appropriate for studying the dynamic classroom situation. Studies that focus on understanding what goes on in chemistry classrooms are especially useful if one is trying to improve the teaching and learning of chemistry. Without a clear understanding of how what is currently being done succeeds or fails, efforts to improve chemistry classrooms will be hit or miss at best.

Theoretical Paradigms

A qualitative research methodology is not one with which most chemists are comfortable. It is diametrically opposed to standard experimental research although the historical development of science has its roots in qualitative techniques.

As opposed to experimental research that is primarily theory driven or deductive, qualitative research is inductive. It begins with a set of observed phenomena from which patterns are identified and a theory developed. Standard experimental approaches view reality as objective, but qualitative researchers tend to see reality as subjective where truth is considered a construct of the individual. Experimental research focuses on that which can be observed, whereas qualitative researchers are interested in studying nonobservables such as meaning, thinking, and attitude. Research done in the experimental paradigm is characterized by controlled experiments which use tests or quantified behaviors as means of gathering data. Qualitative research might employ quantifiable data, but much of the data in this type of research is narrative.

When you ask research questions about personal cognition and meaning, then merely looking at quantified behavior is not a sufficient research design. A different research approach is needed to get at the meanings individuals attach to their actions. Anthropologists and sociologists have been interested in this type of inquiry for many years so it makes sense to look to them for methods of research. Qualitative methodologies have been refined by anthropologists and sociologists for the purposes of studying people, their cultures and interactions. These methods can be equally illuminating when applied to the people in the culture of chemistry classrooms.

The Methodology

Designing a qualitative study completely before entering the research site is problematic because much of the design is emergent and holistic. For example, it is hard to talk about data collection without talking about data analysis because once data collection starts, analysis starts and this analysis effects the data collected subsequently. Once the researcher enters the setting, he/she can and should be working at various points of the research process simultaneously. Change is expected and anticipated in qualitative research and this state of constant change helps to define the emergent design (1). Intentions with respect to design can be expressed, but enough flexibility must be allowed so the researcher can attend to the needs of the setting. Due to the rather global nature of qualitative research, it is difficult to discuss the important elements in sequential steps. The following questions are presented to make the discussion of research design easier; no hierarchical relationships are assumed. Specific comments relating to a model study are typeset in italics

What is the setting investigated? Who are the participants or subjects of the study?

Choices of what to study and who to talk to are not random, but very purposeful. Since there is a need to understand what takes place in chemistry classrooms in order to improve chemical education, the setting choice for our purposes seems clear; chemistry classrooms. These chemistry classes could be lecture settings or laboratory settings at the precollege or college level depending upon what the researcher is trying to learn in a particular study.

Qualitative researchers use participants within the setting as other researchers or observers. These individuals are called informants. The term informant denotes the important role these individuals will play in providing information to the researcher from a unique and personal perspective. The choosing of informants is premeditated so as to maximize the scope and range of information obtained. These informants can represent extreme or deviant cases, typical cases, maximum variation cases, critical cases, politically important or sensitive cases, and convenient cases depending on the needs and purposes of the study (1).

For example, a possible research setting could be introductory chemistry classes at a moderately sized metropolitan university. Two classes are included in the study; one first-semester nonmajors course and one second-semester majors course. Both of the courses in the study are taught in large lecture halls and exceed 100 students. Students to be interviewed have been selected in a variety of ways. One group is self selected. These are students who come to tell you things because they think you ought to know. Others were selected to represent class extremes: high achievers, low achievers, declared majors, undeclared majors, traditional students, and nottraditional students, for example.

What is the focus and purpose of the study? What are the research questions?

In any research project, decisions must be made about the research question or questions that will guide the study. Some questions are interesting and important, but not easily approached from a experimental perspective like: What are the teachers' beliefs about the act of teaching? What does the teacher believe about the way the learning occurs? Is learning in science different from learning in other areas? What are the teachers' beliefs about the students in the classroom? Do science majors think or respond differently from nonscience majors? What do the students believe about the nature of science? Why are some teachers able to make changes in their approaches and others seem paralyzed in their pedagogy? The answers to many of these questions lie within the people in the setting and can be answered only through close contact with the participants. Problem statements in qualitative research are broad because the importance of specific variables often comes from the participants in the classroom and is not decided by the researcher in advance. Often qualitative research questions are open-ended allowing for focus to develop once the researcher enters the setting to be studied. Sub-questions are developed in many studies to provide focus in a small area. It also is possible for the original research question to become secondary in the course of the study.

For the purposes of this discussion, we will consider the research question: How do students respond to a more interactive teaching style in introductory college chemistry? This question could develop into more specific questions like: How do college chemistry students respond to qualitative problem solving activities? Why do science majors and science nonmajors respond differently to interactive, qualitative problem solving activities? and How do we indoctrinate science majors into the culture of science?

What research model or design will be used?

The type of questions being asked should help to determine the elements of the research design. General research models include ethnography, case study analysis, survey analysis, experimentation, standardized observation, simulation, and historical or documentational analysis. Within a qualitative design, a researcher may choose to incorporate more than one research model. Each of these models captures a slightly different view of the participants experience. Using a variety of models allows the researcher to cross check data from a variety of perspectives which is called triangulation of the data. Each researcher should make design choices based upon what they are trying to learn and their theoretical perspectives.

The questions asked above lend themselves nicely to classroom research that uses a large amount of observation combined with interviews of various participants. Observations are made daily throughout the semester. Secondary information is obtained from classroom artifacts and test scores.

What is the researcher's experience coming into the setting and what roles will the researcher assume in the study?

Since the researcher is an important data collection instrument in qualitative research, it is important that the reader know what type of filter is being used to collect the data. What is the researcher's background and experience? Is the researcher sympathetic to the situation or antagonistic? No one enters a research setting objectively. Everything an individual observes is colored in part by his/her experiences as a human being. This is not something that should be apologized for, but it is something that should be admitted. When reading a report of qualitative research, the reader needs to know those things about the re-

searcher that are affecting his/her choices in the research setting.

A complete understanding of the researcher includes an explanation of the researchers theoretical underpinnings and the role that theory will play in the collection and analysis of data. The place of theory needs to be clear in the mind of the researcher, and it should be spelled out in the reporting of the research. In this way, the researcher makes everyone aware of theoretical assumptions and the perspectives being used to view the research.

In addition to understanding the researchers experiences prior to entering the setting, one also should be made aware of the role the researcher assumed in the setting where the data was collected. Since most classroom research involves observations of classrooms, it is important to let the reader know what the researchers place was in the environment. The role of the researcher, like much of the design, grows and develops throughout the time in the classroom.

In the model research being discussed, the role of the researcher is that of both teacher and researcher. Being the teacher gives the researcher access to information that an outside researcher would not necessarily have, but it also limits the type of information students are willing to divulge or at least it could. The researcher is a constructivist, which has implications for how meaningful learning will be defined. The researcher is a former high school chemistry teacher and considered 40 students in a class excessive which colors her view of auditorium-lecture series style chemistry.

What data collection strategies are used in the study?

Since observations are so crucial to qualitative research, daily records should be kept both written and mechanically recorded. A variety of perspectives are gained by asking certain individuals in addition to the researcher to keep daily journals of classroom interactions. Mechanically recording classroom interactions using either an audio- or videotape provides another data source. Interviews with participants in the classroom or influential individuals associated with the classroom provide valuable insights into the meanings behind the observed behaviors. In any research, one piece of data may be important, but rarely sufficient for making a strong case, so it is important to look at issues from several points of view. This triangulation of the data strengthens the assertions that come from the research.

Participant observation is the primary data collection method used in this classroom research. Qualitative researchers do not purposely manipulate the situations they study, but the researcher is a part of the environment and that may make a difference in data. Observations and interviews are audiotaped to strengthen the fidelity of the data without being as threatening to the respondents as videotaping might be. Field notes should include nonverbal class interactions, information written on the board and personal insights of the researcher or research assistants. The teacher-researcher keeps a journal of classroom interactions into which daily entries are made. Graduate assistants are used to help collect data by keeping field notes during class. Students are interviewed in order to gain their perspective of what happens in class and to gain insight into their personal histories. Artifacts are collected from the classes being studied and from other sections of the class taught by different instructors. Interviews, both formal and informal, were conducted with a variety of students.

The reporting of data is important in qualitative research, but it consumes time and space. Here is some sample data collected in the model study.

I asked the class (202) Why does salt melt ice on the roads and help homemade ice cream to freeze faster? They just looked at me. Staring blankly. A few of them smiled at me or gave a thoughtful, hum? No one revealed any great misconceptions or

discussed what the problem was... nothing. After a while I got frustrated and just told them and moved on. I need to get tougher—stop for a while and make them discuss it with me. They are improving some. I get better questions before and after class. Something besides what's going to be on the test? (Journal notes: Sept 4).

Class (101) was good today—started out with colligative properties. Calculating new freezing points and boiling points etc. I asked the question: How can salt be used to clear highways and to freeze ice cream? We talked for a while...

Mindy: Are you using different types of salt?

Dr. P: Good thinking—There are different types of salt but these two processes will work with the same salt, say NaCl for both of them.

David: Energy is released from melting ice—

Dr. P: Ok, so why doesn't it melt the ice cream?

David: Ok, energy is absorbed...

Sally: Then why doesn't it freeze the road harder?

David: Oh! I see the problem.

Karen: Does it have something to do with cars running over it and pushing it down?

Dr. P: ...what do you mean?

Karen: Well, I don't know. Help me out here guys, I'm dying (laughing with the class)

So we went back and reviewed what happens in general to freezing point in solutions.

Dr. P: For a solution, the freezing point does what?

Class (choral): Goes down.

Dr. P: Why does the addition of salt melt icy roads and enhance the freezing of ice cream?

Chris: It's warmer outside than the freezing point of the solution so the ice melts—right?

Dr. P: Does that make sense?

Karen: Then maybe the cars do help because they push the salt down and help make the solution... maybe?

Dr. P: Ok, maybe. What about the ice cream?

David: The freezing point is lowered so the temperature of the solution can go down below zero....

Dr. P: What is the temperature of a glass of ice water?

Class (choral): Zero Celsius.

Dr. P: What is the temperature of ice water with salt in it?

Class (choral): Less than zero?

Dr. P: Right.

(Field notes and transcriptions December 4).

What techniques are used to analyze the data collected during the study?

Data analysis starts as soon as the first piece of data is collected. The data is read back through or transcribed and the researcher begins to question what she sees, hears, and feels. Everyday is colored by the previous day. The analysis of early data provides information that can guide subsequent observations and data collection.

The analysis approach employed in many types of qualitative research is called constant comparison technique (2). In this technique, the data is read and reread and then separated into meaningful chunks. The meaningful chunks are grouped together into categories based on similarities. The data in each category are reread and a description is written of that category that defines the data in it and delineates it from other categories. This does not exclude chunks of data being in two different categories. The categories are not usually pre-established, but emerge from the data. Finally, the categories are reviewed and general themes are sought.

In the sample research, the researcher might place the first piece of data above into a category entitled Why ask why?. Alone this little excerpt does not reveal much, but in this category one might also find chunks of data like:

Yesterday Eddie came by to shed some light on my suspicion about why 202 students are so tight lipped (Field notes 12/5).

Eddie: We're supposed to know something, so when we don't know, we certainly aren't going to tell you or admit it.

Dr. P: Why not?

Eddie: Because we don't want anyone to know we don't know.

Field notes 12/13: Eddie and Kelli came by to talk about the test.

Eddie: Science students are competing against each other sort of. No one is willing to risk being wrong in front of the whole class. Everyone is convinced that everyone else knows what is going on, and no one will open his mouth to verify that fact. You see I feel like I'm faking it in most of my science classes especially chemistry and physics. I don't know the whys.

This category is primarily about science majors and their reluctance to value open-ended conceptual type problems—a reluctance to address the whys of a situation. These are problems they often referred to as having no meaning. Some of this data was sought because of the lack of response the teacher/researcher received from the students in the science majors class which is an example of the influence of early analysis on the collection of data in the later stages of a study. Other chunks of data in this category would include examples of students questioning why an explanation problem is weighted so heavily on an exam or more chunks of non-response in class and on exams when asked an open-ended problem-solving type question. After a set of categories has been developed, the researcher must look at the whole picture to derive the lessons found in the research.

What did you learn from the study?

The results of qualitative studies are hard to report primarily because of the voluminous amount of rich narrative data found in most research of this type. The detail required to make the information meaningful is often an impediment that must be overcome when trying to get the results in print. Some journals are becoming more sensitive to the challenges of reporting qualitative research, and researchers engaged in the methodology are developing agreed-upon formats for reporting results that are more concise. Often the results of a qualitative study are reported in several papers each one looking at a different part of the research. It also is common for specific lessons to be put forth in the form of assertions that summarize several important trends in the data.

Some assertions from the model research being discussed are listed below. This method of reporting results is very efficient, but much of the richness of the data is lost.

- Assertion: Science majors are more concerned about being wrong than nonscience majors and, therefore, less willing to engage in conceptual problem solving.
- Assertion: Science majors have learned to devalue problem solving that is not mathematical and instruction that is not geared to helping them achieve the correct numerical response.

Credibility

All researchers should be concerned about the credibility of their work. Although it is somewhat unusual to apply the terms validity and reliability to qualitative research, credibility is still of utmost importance. In this section, the issue of credibility of classroom research will be discussed in terms of validity and reliability because these are words that are understood by researchers using other methodologies.

It is important in any research to insure that the conclusions drawn are valid. Researchers want to be sure that they are seeing what they think they are seeing. Validity, especially internal validity, is a strength of qualitative research. Since the research is so participant driven with the beliefs and concerns of the students and teachers in the classroom being paramount, internal validity is extremely

high. There are several things that qualitative researchers do to strengthen the validity of their work. First, long periods of time are spent in the setting, which allows for further refinement of assertions and for rechecking of conclusions with participants. Second, when informant interviews are used the language and symbolism of the participants are the units of communication which is less abstract than many instruments used in other research designs. The words used in the interview make sense to the person being interviewed, and there is an opportunity to clarify meaning between the participants and the researcher. Third, participant observation is conducted in natural settings that reflect the reality of the life experiences of participants more accurately than do more contrived or laboratory setting (3). Finally, in addition to things that are part of the research design, the finished product is given to the participants for their responses as a final check of internal validity. The participants are given an opportunity to negotiate changes in what is reported if they are dissatisfied and can convince the researcher of their interpretations. If a common conclusion or set of conclusions cannot be reached, the participants are given the opportunity to rebut the findings in a separate chapter of the work or in a companion paper.

External validity usually refers to the level of generalizability of research conclusions, which is not a goal of qualitative research. Since the term generalizability is a statistical construct, it has little meaning in qualitative research. This is not to say that what is learned through qualitative research is not useful to other people in other settings. Although the uniqueness of individual classrooms can be argued compellingly the similarities between chemistry classrooms in a variety of settings are striking. Qualitative researchers are interested in the comparability and the translatability of their findings. Comparability refers to the degree to which the components of a study are sufficiently well described and defined so that other researchers can use the results of the study as a basis for comparison with other studies addressing related issues. Translatability refers to how well the researcher uses theoretical frameworks, definitions and techniques that are understood by other researchers doing work in the same or related disciplines (3). Comparability and translatability are insured by meticulous disclosures and descriptions of the setting in which the research is done and other factors of the research suitable for comparison such as methods of selection, history of the setting and the study, and a clear statement of constructs. In this way, those reading the results of the work can make decisions about how nearly their situations match the research setting and, therefore, how appropriate the results would be for their situation.

Reliability is a more difficult problem for qualitative researchers since exact duplication of a study is not possible. It can be argued that as long as humans are involved in research, no study can be replicated exactly—regardless of methods employed. Reliability for a qualitative study hinges upon the clear presentation of the data and the results from a given setting. The researcher's ability to completely disclose exactly what is done, and the role the researcher plays is paramount to insuring high levels of external reliability. Since the observations of the researcher are so central to the data collected and the way it is interpreted, it is important that the biases and perspectives of the researcher are also made explicit up front. Other areas that should be discussed in detail with respect

to external reliability include informant choice, social situations and conditions, and methods of data collection and analysis.

Internal reliability is a particularly important issue when qualitative research is done in teams and/or in several sites. The question you are interested in with internal reliability is, "Can others see it as you do?" Below are specifics that a researcher can do to help increase the level of internal reliability.

- Verbatim accounts of raw data should be included in the report of research.
- Multiple researchers should agree on categorization of data.
- Participant researchers should read descriptions and confirm interpretations.
- Data should be recorded mechanically so that verbatim accounts can be coded and classified.

Summary

Throughout this discussion of qualitative research, it is clear that the setting, the participants, and the researcher are all key elements of the research each of which has a dramatic effect on the data that is collected and the way in which it is interpreted. Often qualitative researchers do not let this specificity of site and personnel concern them, because they are interested in the setting that is being studied. As a consumer of qualitative research, one has a right to ask; what good is this to the greater community at large?

When reporting the research, a sense of the setting and its participants should be delineated clearly. As the consumer, one should read this account and ask herself how similar her situation is to this one. If the two settings are very similar, then the lessons learned by the researcher may have meaning in this new situation. If the settings are very different, then one should read the research to see if any of it rings true for his/her situation. If it does not, then one may have opened another interesting door for further research.

Perhaps the most beneficial aspect of qualitative classroom research, is that it provides the reader an opportunity to hear students and teachers. The voices of students often are unheard especially in large lecture classrooms at large universities. The questions my students ask have been asked by other students and have gone unasked by even more students. Qualitative research provides a method useful for exposing these voices especially for professors who find themselves teaching in rooms full of voiceless faces in a large university.

In the rush to change curriculum and practice, teachers' voices are often overlooked as well. When one engages in a qualitative classroom study, the background noise that fills all classrooms is examined and valued. The voices of the participants in the classroom are listened to and as consumers, we have an opportunity to hear things perhaps in a new way. Qualitative research provides the opportunity to see the ordinary in an extraordinary light. This should help to inform the chemistry community as we try to improve instruction and curriculum in chemistry classes in a variety of settings.

Literature Cited

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