Award Address

Twenty Years of Learning: How To Do Research in Chemical Education[1]

2003 George C. Pimentel Award, sponsored by Dow Chemical Co.

by George M. Bodner

It is twenty years since the first symposium on research in chemical education was held at the American Chemical Society meeting in St. Louis in 1984. Over the course of two decades, the number of people who have devoted their careers to doing research on the teaching and learning of chemistry has increased significantly. There have also been significant developments in the methodology for doing research in this area and in the sophistication of the questions being investigated. This paper tries to summarize some of what the author has learned while working with graduate students pursuing research-based M.S. and/or Ph.D. degrees in chemical education over the last 20 years. It describes the three fundamental elements of a good research study—the theoretical framework, the methodological framework, and the guiding research questions—and examines the process by which the choice of theoretical framework is made.

Fundamental Assertion about Research Design

There is general agreement among individuals who teach graduate courses on educational research that a good Ph.D. dissertation proposal contains three fundamental components: A theoretical framework upon which the research will be built; a set of guiding research questions that are consistent with the theoretical framework, which the research will try to answer; and a methodology that is appropriate for probing the guiding research questions. This is the order in which these components might be described in the proposal, but it isn't the order in which the elements are generated. The first step toward a research proposal often involves the construction of a draft of the guiding research questions.

Guiding Research Questions

The most fundamental assertion about guiding research questions is also the most obvious; it is difficult to find answers to questions you don't ask. You can't base a study on the assumption that you'll just "observe what happens."

Research questions not only can but should evolve over the course of a study. Indeed, our experience suggests that when changes do not arise in the research questions during the course of a study, we've probably not asked the right question. To illustrate how research questions evolve during a study, let's look at the work of David Gardner, whose Ph.D. dissertation was entitled "Learning in Quantum Mechanics" *(1).* In his dissertation, Gardner notes that his original question was "How do students learn quantum mechanics?" He then points out that the simplistic answer was: "Not very well." Unfortunately, this answer provides no insight into the problems students encounter with quantum mechanics or how to correct them. The guiding research questions were, therefore, refined and narrowed as the study evolved.

With time, his work became directed by three questions. The first question—*What are the experiences of students learning quantum mechanics*?—came from one of the theoretical frameworks for his study: phenomenography. The second question—*What conceptual difficulties do students have with quantum mechanics*?—came from the other theoretical framework: constructivism. The third question—*How do students approach learning quantum mechanics?*—is consistent with both theoretical frameworks for the study, but arose as a result of interactions with the data as it was being collected, which indicated that many of the students' problems with quantum mechanics were the result of inappropriate strategies they used for studying and doing homework, not difficulties with the concepts of quantum mechanics.

The Choice of Methodology

A few years ago, an article by John Bailar III and Heather Gornik, "Cancer Undefeated" appeared in *The New England Journal of Medicine (2).* Bailar and Gornik's paper was a response to the National Cancer Institute's call for ways to measure progress against cancer *(3).* Their approach was based on an analysis of age-adjusted mortality rates due to cancer from 1950 through 1994 because it "focuses attention on the outcome that is most reliably reported". In an earlier article Bailar and Smith *(4)* had concluded that "35 years of intense effort focused largely on improving treatment must be judged a qualified failure". Bailar and Gornik argued that "with 12 more years of data and experience, we see little reason to change that conclusion …"

As noted elsewhere *(5),* this work provides a metaphor on which discussions of the choice of methodology can be based because it illustrates the effect that this choice can have on the conclusions reached in a research study. There is reason to believe that different conclusions might have been reached if Bailar and Gornik had chosen to examine other forms of progress against cancer that are more difficult to quantitate, such as changes in the quality of life after cancer has been diagnosed.

Quantitative Research

Twenty years ago, graduate students involved in educational research began their introduction to research by taking at least two courses in statistics. They then went on to

take a course on research design that was often based on the book by Campbell and Stanley *(6),* which was originally published in the first edition of the *Handbook of Research on Teaching (7).* This work summarized the classic experimental/control approach to research design and, in general, probed ways in which experimental design could be made more scientific, more quantitative, more objective, and so on. When circumstances precluded the design of a true "experimental" study, Campbell and Stanley suggested ways in which it could become at least "quasi-experimental".

The experimental or quasi-experimental approach to research design endorsed by Campbell and Stanley is still in use today; a new version of this classic text was published only last year *(8).* Any discussion of the choice of research methodology should, therefore, start by recognizing that there is nothing inherently wrong with traditional statistics-based quantitative research. But, then again, there is nothing inherently right about quantitative research, either. Quantitative work isn't intrinsically better, or worse. As Patton *(9)* notes, some questions lend themselves to quantitative techniques; others can only be answered using qualitative methods. Patton (*9,* p 146) raises an interesting point, however, when he argues that quantitative research gives answers to questions of *more*—which class learns more material, which approach leads to the retention of more students or helps students retain more information. Qualitative research provides answers to questions of *better* —do PChem students make better decisions about the way they study quantum mechanics; do organic chemistry students exhibit a better understanding of the arrow-pushing formalism; and so on.

Proponents of quantitative methods are likely to agree with Patton (*9,* p 20), who noted that "Quantitative methods are succinct, parsimonious, and easily aggregated for analysis; quantitative data are systematic, standardized, and easily presented in a short space". And yet, there are potential problems with quantitative research. It tends to focus on the average student and can lead to erroneous conclusions if the change being studied benefits some students and not others. It is often atheoretical—as opposed to qualitative research, which is based on an explicit theoretical perspective. By its very nature, quantitative research focuses on things that can be measured quantitatively, such as student performance on exams, which are often influenced by so many confounding variables it is difficult to tease out the effect one is looking for. When the sample size is large, one can obtain results that are statistically significant, but not necessarily important. When the sample size is small, one often gets no statistically significant difference, even when there is anecdotal evidence that an effect exists.

For some, quantitative research is better because it is based on "cold," "hard," "objective" data. Namenwirth, however, has questioned the myth of the objective scientist *(10).*

> Scientists are no more protected from political and cultural influence than other citizens. By draping their scientific activities in claims of neutrality, detachment, and objectivity, scientists augment the perceived importance of their views, absolve themselves of social responsibility for the applications of their work, and leave their (unconscious) minds wide open to political and cultural assumptions. ... while scientists firmly believe that as long as they are not *conscious* of any bias or political agenda, they are neutral and objective, ... in fact they are only unconscious.

To illustrate the effect of the choice of methodology on research results, let's examine just one of many possible examples. Treagust, Harrison, and Venville *(11)* studied the effect of using analogies to teach students. They found that there was no difference in the quantitative achievement scores on a traditional exam on optics for students who had been taught with analogies and those who had not. The students who had been taught with analogies, however, demonstrated a higher level of conceptual understanding when they were interviewed using qualitative methods.

Shift in Educational Research

Although the chapter on experimental and quasi-experimental designs by Campbell and Stanley appeared in the first edition of the *Handbook of Research on Teaching* in 1963, a similar chapter did not appear in either the second *(12)* or the third edition *(13)* of this book. This can be taken as evidence for a gradual shift in the way educational research is designed and carried out. In the *Handbook of Research Design in Mathematics*, Lesh and Kelly *(14)* describe this shift as moving away from assumptions of "objectivity"; from viewing the student as a lone, passive learner; from relying on simple correlational models; and from relying on one-time measures of achievement such as standardized tests. They advocate moving toward viewing the researcher as a participant–observer who practices self-reflexivity; toward viewing the learner both as an individual and as a social learner in a complex classroom environment; and toward collecting thick, ethnographic descriptions that recognize the theory-ladenness of observation and method.

Qualitative Methodology

Schwandt *(15)* notes that the term *qualitative* is a "not-so-descriptive adjective" attached to various methods of scholarly inquiry that rely on data in the form of words, as opposed to quantitative techniques that generate a product expressible in numbers. The primary sources of data for qualitative research are in-depth, open-ended interviews or "think-aloud" problem-solving sessions; field notes taken during observations of classes or during interviews the researcher has conducted; and written documents in the form of reflective journals.

Qualitative research sacrifices the objectivity that results from rigid statistical research designs for a combination of flexibility, depth, and detail. The flexibility of qualitative research was captured by Lincoln and Guba *(16)* who argued that "… the design of naturalistic inquiry … *cannot* be given in advance; it must emerge, develop, unfold." The depth and detail that are characteristic of qualitative research were captured by Geertz *(17),* who noted that qualitative studies produce rich, detailed descriptions of people and places—which

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he called "thick descriptions"—that enable readers to interpret for themselves the meaning and significance of the research.

Qualitative research is done by individuals with a preference for inductive, hypothesis-generating research, rather than hypothesis-testing research *(18)*. The increasing number of books devoted to qualitative research methods is testament to the growth in the popularity of this technique *(19–30)*.

Mixed Methods for Educational Research

In the late 1970s, most of the papers presented at meetings of the *National Association for Research in Science Teaching* were based on quantitative research designs. The 1980s, however, were a period of the "paradigm wars" *(31)*, during which proponents of the traditional, quantitative, experimental, or quasi-experimental paradigm fought pitched battles with advocates of a naturalistic, qualitative approach to research.

At the height of the paradigm wars, it was common to encounter individuals who argued that one had to choose between quantitative and qualitative techniques; they could not be combined in a single study. Patton (*9,* p 14) questions this attitude and argues that qualitative and quantitative methods "constitute alternative, but not mutually exclusive, strategies for research." The best evidence that the paradigm wars may have ended is the appearance of books that explicitly describe combining qualitative and quantitative approaches *(32, 33)*.

Action Research

Several years ago, the author published a paper on Action Research that began as follows *(5)*: "Each time we make significant changes in what we teach or how we teach we are faced with the same question: How can we find out whether the innovation we have brought into our classroom is worthwhile?" One of the advantages of learning how to do educational research is the opportunity to master some of the techniques needed to answer questions such as this.

Chemists have traditionally assumed that the best way to address these questions is to compare student performance on a common exam for an experimental versus control group. We have argued that: "By focusing on how much is learned, the traditional experiment fails to measure differences in *what is learned.* Or what knowledge is *retained*. Or whether a new instructional technique leads to improvement in students' understanding of knowledge we *value*, rather than knowledge that can be easily tested" *(5)*.

Action Research is based on the assumption that any significant change in instruction will have an effect. Whereas the traditional experiment presumes that the change being made either benefits students or it does not, Action Research assumes that some students will benefit from the change, while others will not. It therefore allows one to target a change on a particular group of students, for example, the "C" students in one case, the "B" students in another.

Action Research is a cyclic process in which a change is made, the effect of the change is studied, and modifications are made whose goal is to increase the positive effects and minimize any negative effects on the target population. Details about the implementation of Action Research, the theoretical basis on which it is built, and sources of further information about this technique can be found in our previous paper *(5)*.

Theoretical Perspectives or Framework

Kuhn *(34)* differentiated between research that is based on a paradigm and that which is not. He argued that paradigms make research more effective by helping researchers select problems that can be solved and by suggesting appropriate methods for collecting data to solve these problems. In educational research, the theoretical framework serves a similar function. It provides the assumptions that guide the research, helps the researcher choose appropriate questions for a given study, and directs the researcher toward data collection methods that are appropriate for the study.

Those who are learning how to do educational research face two major challenges. They must first try to understand some of the theoretical perspectives on which they might base their research. They then have to decide which of these frameworks are inappropriate for addressing the questions they want to answer and select the theoretical framework(s) that is (are) appropriate.

The first reference given to anyone who comes to the author for advice on research design is the book on qualitative research by Patton *(9, 35)*. Patton does a good job describing various theoretical frameworks, some of which are summarized in the List below. For our purposes, it is useful to recognize that the research perspectives in this list all have both theoretical and methodological components.

Some of the theoretical perspectives in List 1 are incompatible, but others are not. Thus, there is nothing inherently wrong in having more than one theoretical perspective for a long-term research project, or even for a particular study within this project. The author argues that you don't have to accept all of the assumptions of a given theoretical framework, as it is described by various authors, when you apply it to a study. But you need to be explicit about which assumptions are applicable to a given study. Finally, it is important to accept the notion that Patton *(9)* argues for so cogently: Some studies simply are not theory-based.

Examples of Theoretical Perspectives

Conversations with colleagues who teach research methods courses suggested that there are relatively few places to which you can refer beginning researchers to help them choose an appropriate theoretical perspective *(9, 36–38)*. There was, therefore, support for the notion of an article, such as this, which describes a handful of popular theoretical perspectives. The order in which these theoretical perspectives are discussed is somewhat arbitrary, and, in most cases,

more than one study from our group could be used to illustrate a given perspective.

Constructivism

The theoretical framework known as constructivism can be summarized as follows: "Knowledge is constructed in the mind of the learner" *(39–47)*. This theoretical framework assumes that we don't discover knowledge; we actively construct it. We invent concepts and models to make sense of our experiences. We then continually test and modify these constructions in the light of new experiences.

In his first paper on constructivism *(39),* the author focused on a view of this theory of learning that has become known as *personal constructivism*, which concentrates on the individual knower and acts of cognition. In that paper, he traced the evolution of constructivism back to the work of Jean Piaget and introduced the idea of *radical constructivism*. A second paper described an alternative form of personal constructivism that arose from the work of the clinical psychologist George Kelly and introduced another form of constructivism known as *social constructivism*, which focuses on social interactions that explain how members of a group come to share an understanding of specific life circumstances *(43)*.

Some have been tempted to think about radical constructivism *(43, 45)* and social constructivism *(46, 47)* as opposite ends of a continuum. At one end, learners construct knowledge in isolation, based on their experiences of the world in which they live. At the other end, learning is embedded in social and cultural factors. Most situations in which learning occurs, however, fall somewhere between these two extremes. Learning is a complex process that occurs within a social context, as the social constructivists point out, but it is ultimately the individual who does the learning, as the radical constructivists would argue.

Research studies based on the constructivist theory often examine the process by which an individual makes sense of his or her experiences. Research design in this area is guided by the assumption that studies of "sense-making" involve more than just collecting observations. Schwandt *(15)* offers the example of the phenomenon of raising one's right hand above one's shoulder as performed by someone hailing a cab, by a student volunteering to answer a question in class, and by a witness testifying in court. The same physical phenomenon is observed, but in each instance the meaning of the action is fundamentally different.

Symbolic Interactionism

The theoretical perspective known as symbolic interactionism comes to us from social psychology. This framework is based on four assumptions: first, that we act toward the objects and individuals in our environment on the basis of the meaning these objects and individuals have for us; second, that these meanings are not determined by an individual's experiences, they are the result of social interactions among individuals; third, that meanings are created and modified through an interpretative process undertaken by an individual member of the group; and finally, that it is these constantly evolving meanings that determine people's actions *(48–51)*.

The term *symbolic* reflects the idea that we communicate through language that is, itself, symbolic. The term *interactionism* emphasizes the role that social interactions have in the construction of knowledge and conceptual understanding. The main goal of the symbolic interactionism researcher is to use observable interactions to identify implied symbolic behavior *(49)*. Researchers who bring a symbolic interactionist framework to a particular study have to actively enter the setting of the people being studied to see their particular definition of the situation, what they take into account, and how they interpret this information. To understand the process of meaning making, the researcher must carefully attend to the overt behaviors, speech, and particular circumstances of behavior in the setting in which interactions take place.

Symbolic interactionism assumes that the researcher must view things through the perspective of those under

List 1. Theoretical Frameworks for Research and Evaluation

Constructivism: Focuses on individuals making sense of their experiences.

Symbolic interactionism: The search for a common set of meanings that emerge from interactions within a group.

Hermeneutics: Providing a voice to individuals or groups who either cannot speak for themselves or are traditionally ignored.

Phenomenology: The search for the common thread or essence of a shared experience.

Phenomenography: The description of different ways people interpret shared experiences.

Critical Theory: Overcoming the uneven balance of power between groups of individuals.

Ethnography: The study of the culture of a group.

Ethnomethodology: The study of people making sense of their experiences to behave in socially acceptable ways.

Grounded Theory: Analysis of fieldwork that is used to generate a theory.

Pragmatism: Answering practical questions that are not theory-based.

Positivist/Realist/Analytic Approaches: The search for the "truth" about the real world, insofar as we can get at it.

Autoethnography: Insights that can be extracted from analysis of one's own experiences.

Narratology: Analysis of a narrative or story to reveal something about the world from which the individual comes.

Systems Theory: Analysis of a system, not the individuals who comprise the system.

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study. As a result, participant observation becomes a key method here; it allows the researcher to place the data being collected into the context of the operating classroom and to participate in the interactions between and among the subjects.

DelCarlo *(52)* used symbolic interactionism to study the ethical philosophies—the "objects" in symbolic interactionist terms—students develop through interactions with other students, research advisors, professors, or TAs in the laboratory setting. She argued that interactions within the classroom lab environment play an important part in the evolution of meanings for the individuals involved in the interaction. This meant that the data on which her study was based had to consist of both observations of actions in the laboratory environment and in-depth interviews outside of the classroom that were designed to uncover individual meanings.

Hermeneutics

The term *hermeneutics* is often traced back to "Hermes," the messenger of the gods in Greek mythology. Hermes not only delivered decrees from Mount Olympus, he interpreted for humans the meaning and intention of the messages he brought *(53)*. Hermes has, therefore, been described as the guide to intelligent speech *(54)* and the Greek word *hermeneuein* is translated as "to interpret."

Hermeneutics has been described as "the art, theory and philosophy of interpreting the meaning of an object (a text, a work of art, social action, the utterances of another speaker, etc.)" *(15)*. Schleiermacher *(55)* argued that hermeneutics is necessary when there is the chance of misunderstanding the meaning of the object. The development of hermeneutics began in the period after the Renaissance, when the principles of interpretation of text were applied to the study of sacred (biblical) texts and texts from classical antiquity *(53)*. Dilthy *(56)* expanded the scope of hermeneutics by raising the following question: If the techniques of hermeneutics could be used to systematically interpret written texts, why not apply them to speeches, conversations, or interviews or even to the "text" of a person's life or experiences?

An important feature of hermeneutics is the notion of the hermeneutic "circle" or "spiral." In order to understand the meaning of a text, the interpreter needs to understand its parts; and yet, in order to understand the different parts of a text, the interpreter needs to understand the whole text. The first interpretation of the text is based on the prior knowledge the researcher brings to the text, but this prior knowledge is changed by reading the text. As a result, the researcher brings a different perspective to the second reading, which changes the knowledge the researcher brings to a third reading, and so on, *ad infinitum*. In practice, however, there is a point at which further readings do not substantively change one's understanding.

Hermeneutics is often used in educational research in the sense of providing a "voice" to those who either cannot speak for themselves or who have not been listened to. It was, therefore, an appropriate framework for an study conducted by Hunter, in which he looked at what happens when "discovery" labs are integrated into the curriculum at a large research university *(57)*.

Phenomenology and Phenomenography

Suppose that you were familiar with the structure of an organic chemistry course. You knew something about the subject matter covered, the kind of textbooks used, the way the course was usually taught, the kind of questions that were likely to appear on exams, and so on. You would have what is called a first-order understanding of the phenomenon of organic chemistry courses. Now, suppose that you were interested in understanding what it means from the students' perspective to "take" organic chemistry. Your goal would be a second-order perspective—an understanding of the students' experience with the course. The traditional paradigm that guides research designed to understand the meaning of human experience is known as *phenomenology (58–59)*.

Phenomenology is based on the work of philosophers such as Husserl, Schutz, Merleau-Ponty, Gadamer, and Ricoeur *(53)*. The characteristics of phenomenology might best be described by paraphrasing the comments of van Manen *(58)*. He defines phenomenology as the study of the world as we experience it, not as we conceptualize or reflect on it. The goal of phenomenology is "a deeper understanding of the nature or meaning of everyday experiences". The focus is on the lived experiences while they are being lived, not after one reflects on them. Phenomenology searches for the "essence" of a phenomenon; the "something" that makes the phenomenon what it is; the "something" without which the phenomenon could not be what it is.

The term *phenomenology* has been used by many researchers to describe studies that don't quite fit the classic definition. Studies that don't assume that "essence" is singular; that there is a common thread that describes the meaning of the experience for everyone who lives it. Our group has, therefore, been quite careful to differentiate between traditional approaches based on phenomenology and those that look similar but are slightly different known as *phenomenography (60, 61)*.

The focus of phenomenography is still on the meaning of an experience. The goal of phenomenography is to understand how people experience, interpret, understand, perceive, and conceptualize a phenomenon *(62)*. Phenomenography assumes that knowledge results from thinking about experiences with people and objects in the world in which we live.

Whereas phenomenology looks for the common essence that characterizes the phenomenon for all who experience it, phenomenography assumes that people can and will experience the same phenomenon in a limited number of ways that are qualitatively different *(63)*. Marton *(64)* captures the essence of phenomenography by noting that it searches for the middle ground between the extremes of "the common" and "the idiosyncratic."

The goal of phenomenography is to understand the phenomenon from the participant's point of view. The researcher therefore tries to act as a "neutral foil" for the ideas expressed by the participants of the study. This does not mean, however, that the researcher is an objective observer akin to a video camera *(65)*. In the course of an interview, the researcher's

knowledge may be used to help the participants better explain what they mean. Entwistle *(66)* argues that richer descriptions can be obtained when the interviewer contributes to the effort to explain the student's interpretation of experiences.

Phenomenographers do not claim that the results of their research represent "truth"; only that their results are useful *(67)*. Marton *(68)* noted that it isn't important whether the participant's conceptions are viewed as "correct" or "incorrect" by others; the goal of the research is to identify the possible conceptions members of a group have of a given phenomenon.

As might be expected, the primary source of data for phenomenography is an open, intensive interview *(69)*. It is open in the sense that there is no prearranged structure to the interview; it is intensive in the sense that the interview follows a given line of questioning until the participant has nothing more to say.

Data analysis begins by having the researcher identify the qualitatively different ways in which different people experience a given concept. One of the potential pitfalls of phenomenography is the tendency to assume that students' accounts of their experiences are the same as the students' experiences. Säljö *(63)* notes that there sometimes appears to be a discrepancy between what researchers observe when they watch a participant go through an experience and the way participants describe their experiences. Säljö, therefore, suggests that we refer to studying people's "accounting practices" of phenomena, instead of referring to studying people's "experiences".

There are several ways in which the results of phenomenographic research can be useful. Entwistle *(66)* noted that students are generally encouraged to develop a conceptual understanding, and that teachers often try to help their students develop concepts that are consistent with those held by experts in the field. Students, however, often have conceptions of a phenomenon that are not consistent with those held by experts. Marton *(58)* claims that "a careful account of the different ways people think about phenomena may help uncover conditions that facilitate the transition from one way of thinking to a qualitatively 'better' perception of reality".

Critical Theory

The critical theory movement was founded in 1923 at the *Institut für Sozialforschung* in Frankfurt, Germany. The first generation of critical theorists included Adorno, Marcuse and Fromm; the most influential modern spokesperson for critical theory is Jürgen Habermas *(70–72)*.

Critical theory calls for reasoning that is practical, moral, and ethically and politically informative. The goal is individual and social transformation via self-knowledge. Critical theory rejects the idea that one can have a disinterested observer who contemplates the system from a distance.

Critical theory often focuses on situations where there is an uneven sharing of power. It therefore often involves discussions of "emancipation." The author endorses the application of critical theory to educational research because of the structure of the traditional teacher-centered classroom, where power lies in the hands of the instructor who decides what is taught (or learned), the order in which it is taught (or learned), the amount of time devoted to a given topic, and so on *(70)*.

Habermas talks about technical knowledge (*techné*) and knowledge that comes from one's view of what is right, or good (*phronesis*). But he also talks about *emancipatory* knowledge, which literally frees the individual. The author's favorite example of emancipatory knowledge is learning how to ride a bicycle as a child. At that moment, the individual is free. There is no longer the need to ask a parent or adult for help getting somewhere; the individual is free to make decisions about where he or she is going on their own.

Critical theory seeks a diversified education for all that creates individuals who can think critically. It assumes that schools can become institutions in which knowledge, values, and social relations are taught to educate students for critical empowerment *(73)*. The ultimate goal of critical theory is a transformation of society into one that is just, rational, and humane.

Ethnography and Ethnomethodology

Ethnography *(74)* is often thought of as a methodological framework, but it has strong theoretical aspects. It has its basis in cultural anthropology, where the goal is describing the behavior of a culture on the basis of first-hand experiences with members of that culture through field studies.

A related theoretical framework known as ethnomethodology was developed by Garfinkel *(75)* as the basis for sociological research. It focuses on how people accomplish the interactions we take for granted in everyday life. Ethnomethodology "… gets at the norms, understandings, and assumptions that are taken for granted by people in a setting because they are so deeply understood that people don't even think about why they do what they do" *(35)*. It is based on descriptive accounts that "… organize and render observable the features of society and social settings" *(76)*.

Ethnomethodology was chosen as the theoretical perspective for a study of how graduate students learn to solve organic synthesis problems *(77)*. This choice of theoretical perspective was based on the assumption that the community of synthetic organic chemists constitutes a culture to which students become acculturated as their understanding of the field develops. This perspective recognizes that synthetic organic chemists routinely use language that is unique to their community; that a well-trained chemist from another discipline wouldn't be able to participate in a conversation between practicing synthetic chemists unless explicit attempts were made to include that individual in the conversation; and that synthetic organic chemists use tools such as retrosynthetic analysis and the arrow-pushing formalism that are unique to this community.

Conclusion

Readers who have reached this point in the manuscript should not be surprised to find that the noted expert on research design, Lee Cronbach, has argued that designing a study is as much an art as it is a science *(78)*. So far, we have

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discussed three of the basic pieces of a study: the theoretical framework, the methods of data collection, and the guiding questions. If these pieces form a coherent, unified whole, then so should the data and the data analysis *(38).*

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Notes

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