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Using Interviews in CER Projects: Options, Considerations, and Limitations

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Using Interviews in CER Projects: Options, Considerations, and Limitations

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Interviews can be a powerful chemistry education research tool. Different from an assessment score or Likert-scale survey number, interviews can provide the researcher with a way to examine and describe what we cannot see, aspects such as feelings, thoughts, or explanations of thinking or behavior. Most people have no doubt seen countless interviews on TV news and talk shows. These sessions might convey interviewing as a spontaneous, easy, and straightforward process. However, using interviews as a meaningful research tool requires considerable thought, preparation, and practice. This chapter provides a general introduction to the use of interviews as a tool within a chemistry education research context. The chapter provides a general introduction to the use of interviews as a research tool including how to plan, conduct, and analyze interviews. It highlights important considerations for designing and conducting fruitful interviews, provides examples of different ways in which interviews have been used effectively in chemistry education research, and supplies additional references for the reader who wants to delve more deeply into particular topics.

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Introduction

Improving teaching and learning in chemistry requires an understanding of what students know and the nature of their difficulties with the content. Well-constructed interviews can provide chemistry education researchers with a rich data set that affords a glimpse into students' thought processes. Furthermore, interviews can help researchers understand what other factors play a role in students' varying levels of success in chemistry. Consider a comparison of different student assessment methods. A multiple choice assessment is quick to grade and can indicate if a student does not understand the material, but it is less likely to ascertain the student's particular difficulty with the material. On the other hand, an open ended question on a test may take longer to grade, but it can better detect the specific problem a student has with the content. Lastly, an oral final exam, which allows for follow-up questions to probe more deeply into a student's understanding of a topic, requires a large investment of time but will allow for the best identification of a student's specific content issues. Interviews are most similar to this last form of assessment. They may take longer to conduct and analyze, but the wealth of information obtained from even just a few student interviews can potentially help improve instruction for the whole class.

Interviews are most useful in answering why and how questions. For example, a multiple choice test or a survey could be used to identify gains in student achievement or attitudes as a result of a particular intervention. Interviews, on the other hand, can help determine *why* these gains are observed or *how* students are applying elements of a particular intervention in solving problems. There are many good books and papers that provide in-depth information regarding interview methods, several of which we cite in this chapter. The goal of this chapter, however, is to provide an overview of important considerations in using interviews as research tools specifically for chemistry education research (CER) and particularly for those new to the use of interviews. Thus, in this chapter we aim to provide examples of two common, but different, types of interviews that have been used successfully in CER studies, and to highlight many practical considerations for planning an interview, conducting an interview, and analyzing interview data. We also point readers to additional resources should they want to delve into any of the topics in more detail.

Types of Interviews

There are several different types of interviews that can be used for data collection in CER. In this chapter we will focus primarily on open-ended and think-aloud interviews, the two types of interviews most commonly used in CER

and thus most likely to be valuable for those new to using interviews as a tool for research.

Table I provides examples of two CER studies that used interviews as their primary data collection tool. One used a structured open-ended interview format while the other used a think-aloud interview protocol. Throughout the chapter we will refer to these two examples, along with other CER references, to discuss the important aspects to be considered when designing, conducting, and analyzing interviews. While there are numerous studies in science education research, and more specifically in CER, that use interviews as data collection methods, few of them actually provide the interview protocols used to obtain the data. In this chapter we have chosen to use as examples only studies for which interview protocols were readily available.

Table I: Examples of the Use of Structured Open-Ended and Think-Aloud Interviews in CER Studies

Type	*Structured, Open-Ended*	*Think-Aloud*
Title and Author(s)	Exploring Conceptual Integration in Student Thinking: Evidence from a Case Study [Taber (*1*)]	"It Gets Me to the Product": How Students Propose Organic Mechanisms [Bhattacharyya & Bodner (*2*)]
Research Question	To what extent do students achieve "conceptual integration" of the science they are learning in school, in particular, across related topics in chemistry and physics?	What strategies do students enrolled in a first-semester graduate level organic chemistry course use to solve mechanistic problems?
Rationale for Type of Interview	In examining how students integrate concepts across subjects, students should be asked in some depth about two potentially related areas of science. A structured interview was chosen as it provided a means to collect data about student thinking over a range of topics within a realistic time span.	In order to make explicit students' organic chemistry problem solving strategies, the researchers chose a think-aloud protocol, asking participants to describe their thoughts while solving a series of organic mechanism problems.

Open-Ended Interviews

Most people are probably familiar with open-ended types of interviews where the interviewer asks a question and the interviewee responds to the question. Although on the surface this may appear to be a fairly easy tool to use, the quality of the data obtained through interviews is highly dependent upon the interviewer and the structure of the interview. Thus, preparing for interviews is very important, and choosing an interview format that is well aligned with the research question(s) and theoretical framework is an essential initial step. There are several different types of open-ended interviews, which may have slightly different names depending on the author (*3-5*), but the main distinguishing feature among them is the level of structure of the interview protocol. Figure 1 depicts the different types of open-ended interviews on a continuum. It should be noted, however, that it is often the case that interview protocols fall into more than one of these categories, with some sections that are more structured and some that are less structured.

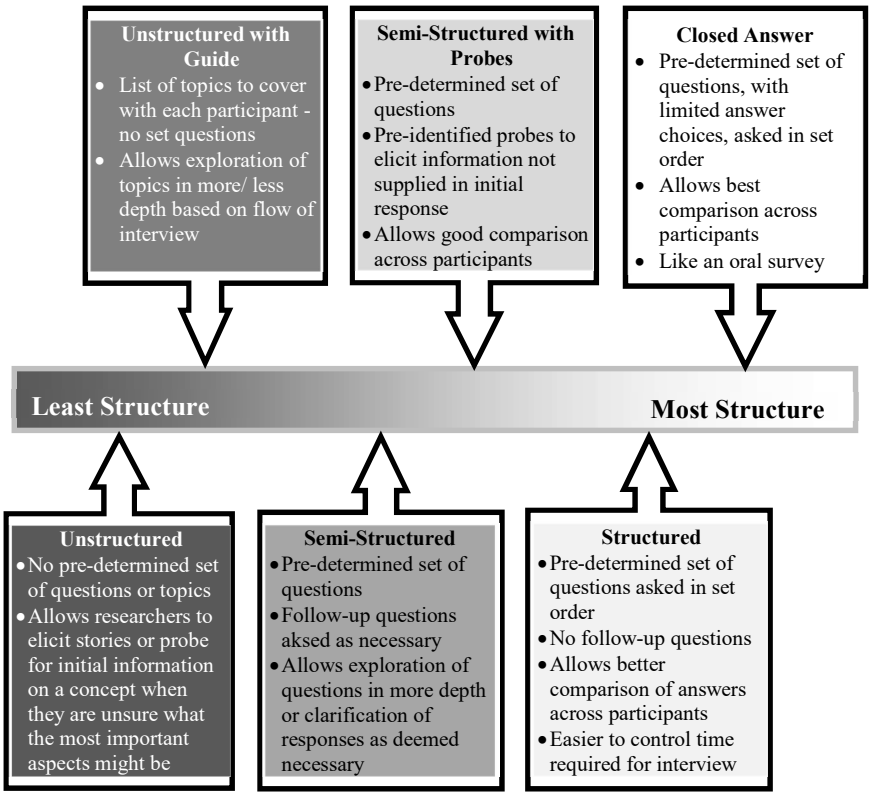

Figure 1: Continuum of Open-Ended Interview Types

Unstructured Interviews

The least structured type of interview is often called an unstructured or conversational interview. This type of interview is most commonly used in ethnographic studies where the researcher is interested in stories or cases where he or she does not know enough about a phenomenon to ask specific questions. In the latter case, the researcher can use information from these interviews to design a more structured interview protocol (*3, 5*). In this type of interview, there is no set of pre-determined interview questions. The interviewer has freedom to pursue any line of questioning that he or she believes will provide interesting and relevant data. In some cases the researcher will have a list of topics to cover during the interview, but the topics are not covered in any particular order nor are there any set questions about these topics.

Unstructured interviews are not very common in CER studies as many CER studies have specific research questions the researchers are interested in answering or a specific chemistry topic they want to focus on. However, some researchers may choose to use unstructured interviews to gather information that can help them develop more structured interview protocols to use in their data collection. One interesting use of an unstructured interview in CER is a recent study designed to identify effective instructional strategies for assisting a visually impaired student in understanding gas laws (*6*). The researchers used tutoring sessions as an initial data source. These sessions were essentially unstructured interviews where the questions were posed by the visually impaired student (the participant). As the tutor (the researcher) responded to those questions, he gained an understanding of the difficulties the student encountered in learning the content.

It is important to note that unstructured interviews require the most skill on the part of the interviewer and make it more difficult to make comparisons across participants. Though those new to the use of interviews as a research tool may view unstructured interviews as the easiest to conduct as there is seemingly little upfront preparation, constructing good interview questions requires careful consideration. During unstructured interviews, the researcher must instinctively, as the interview progresses, determine what questions would best to elicit the desired information in a way that does not bias or lead the participant. Furthermore, the questions asked in unstructured interviews will be different for each participant, which limits the researcher's ability to compare across participants.

Structured Interviews

More structured types of interviews (semi-structured – structured) are much more commonly used in CER studies. These types of interviews have a predetermined set of questions to ask participants and are particularly useful in investigating specific research questions or topics. In a truly structured interview protocol, all participants are asked exactly the same questions in the same order. These types of interview protocols are typically best for studies that want to cover several topics in a limited amount of time. The ability to easily compare responses between participants is important, and researchers are more often interested in participants' knowledge or experience as opposed to their opinions,feelings, or problem solving strategies.

The open-ended study outlined in Table I provides a good example of a study that uses a structured interview protocol (*1*). The goal of this study was to investigate "conceptual integration" across particular related topics in physics and chemistry, and the authors wanted to be able to cover a wide range of topics in a reasonable amount of time as well as compare answers across participants. Carefully choosing the questions that each student was asked prior to the study allowed the researchers to work their way through several topics in about 45 min to 1 hour. Asking all participants the same questions in the same order made it easier for the researchers to compare responses between participants. Moreover, as this study focused primarily on evaluating specific aspects of students' knowledge, the use of follow-up questions to delve more deeply into student responses is arguably not as important here as in studies that are interested in opinions, feelings, etc. Thus, a more structured interview aligns well with this study's research questions and design.

The questions in one small segment of the interview were presented as follows:

- Do you know what the composition [make-up] of an atom of sodium would be?
    - (Can you tell me about the structure [arrangement of parts] of the sodium atom?)
- Do you think that a single sodium atom could fall apart? (Could the outer electron fall out of the atom?) (Why?/Why not?)
- What do you think holds the protons together in atomic nuclei?

The study by Cacciatore and Sevian (*7*), that looked at whether changing a single laboratory experiment could improve students' general chemistry performance, is another good example of the use of a protocol that is closer to the structured end of the continuum. In this paper, the authors report

both their interview questions and the rationale behind each question. For example:

> "**Question:** Which labs were most helpful in learning the lecture material? Why?"
>
> **"Rationale:** Assesses student's beliefs about the connections between lecture and laboratory portions of the chemistry course."

Semi-Structured Interviews

True semi-structured interviewstypically have a pre-determined set of questions, but the order and the exact wording of the questions may differ depending on the participant and his or her responses. Also, semi-structured interview protocols typically involve asking follow-up questions to delve deeper into particular topics of interest or to seek clarification of a participant's response. Semi-structured interviews are best used in studies that examine one or two focused topics in more depth, in studies that are more focused on identifying important similarities and differences and less focused on being able to directly compare responses to particular questions between participants, and in studies that are more focused on students' ideas, opinions, beliefs, etc. as opposed to their knowledge about a topic.

For example, Cole and Todd (*8*) used a semi-structured interview protocol to examine the effects of web-based multimedia homework on student learning in general chemistry. For this study the authors collected several forms of quantitative data (homework, laboratory, and exam scores; standardized test scores (ACT and Math Placement scores); and, a version of the Group Assessment of Logical Thinking) to evaluate the impact on knowledge gains. Interviews were used in conjunction with quantitative data to ascertain students' opinions about the value of on-line homework. Although this chapter focuses only on the use of interviews as a CER tool, the use of both quantitative and qualitative data to obtain a more complete picture is common in many CER studies. For the interview portion of the Cole and Todd study, the interview protocol consisted of a set of 16 questions or topics asked in each of the interviews. However, the order and exact wording of the questions was not necessarily the same for each participant. In the interview protocol for this study (found in the paper's supplemental online material), the authors state that researchers did not use the protocol verbatim, but each interview covered all of the topics listed in the protocol. The types of questions included in this interview protocol vary from straight forward background questions ("Why are you taking chemistry 103?"), to fairly specific opinion questions with pre-identified probes

("Which course tools have helped you learn the most – lecture, discussion, lab, homework, tutorials, demos, videos, animations, online quizzes, group work?"), to more general topics about which the authors wished to elicit student opinions ("Use the response to [question]13 to probe more about the use of videos, animations, etc. on how technology impacts the student's learning").

A study by Howard, et al.(*9*) that examined college students' understanding of atmospheric ozone formation also used semi-structured interviews as a research tool. This study, however, used a "semi-structured with probes" protocol. The researchers asked each student a common a set of questions and had a related subset of probing questions for each primary question that were used as needed. Given that this study was more interested in student knowledge (understanding of atmospheric ozone formation), an interview protocol towards the more structured end of the spectrum is reasonable. In this interview protocol, students were presented with a series of figures, problems, or situations related to atmospheric ozone formation about which students were then asked a series of questions. Some of these questions had additional follow-up questions that were used depending on the participant's response. For example, in the first interview question students were presented with a figure that represented the main cyclic tropospheric ozone formation components. They were then asked, "Can you explain what is happening in the Figure?" Depending on the participant's response, the follow-up probe ("Can you describe what NO, NO_2, and $HO^{\bullet}$ are, and their significance to our atmosphere?") may also have been used.

Although this section of the chapter has tried to delineate the differences between unstructured, semi-structured, and structured interview protocols, it is important to remember that as illustrated in Figure 1, these interview types really represent a continuum. Furthermore, it is possible to combine different types of interviews within one interview protocol with some sections of the protocol being more structured and others being more semi-structured, or even unstructured. In general, a more structured protocol is advised for people new to interviewing. This allows the researcher to spend time developing questions that will elicit sought after information and to avoid using questions that could bias or lead the participant to particular answers (see section on writing interview questions). A more structured protocol is also useful if more than one researcher will be conducting interviews as it helps to minimize variation between interviewers (*3*).

Focus Group Interviews

Often interviews are thought of as a one-on-one conversation between the interviewer and the interviewee; however, an alternative to this format is the focus group interview. Focus group interviews are commonly used in

educational research. Although originally developed for social psychological research purposes, focus group interviews became heavily associated with consumer market researchers in the 1950s, and have only more recently, beginning largely in the 1980s, been used in academic social research (*10*). One common use of focus group interviews for academic social research is program evaluations, such as the assessment of an undergraduate chemistry program (*11*).

A focus group interview is essentially a discussion between a small group of individuals about a particular topic that is facilitated by a moderator (the researcher). In many ways focus group interviews are similar to one-on-one open ended interviews and thus many of the same considerations for "regular" open-ended interviews can be applied to focus group interviews. For example, focus group interviews can be unstructured (aimed at gathering data to explore a new domain by encouraging a wide variety of viewpoints on a topic) or more structured in format. The use of interview questions that do not bias or lead the participants is crucial to obtaining meaningful information. Additionally, good alignment of research questions, design, and interview format is important. Yet, there are several considerations and benefits unique to focus group interviews that are highlighted in this section (for readers looking for more information about the use of focus group interviews see Liamputtong (*12*)).

In general, focus groups should be small, about 4-8 people, to allow everyone to have a chance to speak. Although general considerations for participant selection, discussed later in this chapter, should also be applied for focus group interviews, the quality of data obtained from a focus group interview is largely dependent upon how comfortable the participants feel discussing ideas and offering alternative opinions. Thus, it is important to choose participants who have experiences that allow them to contribute to the conversation and who are similar enough that they will feel comfortable expressing their opinions in the group. An important role of the researcher in focus groups is to ensure that everyone has the opportunity to speak and that the level of threat is kept to a minimum. This is to ensure the freedom to share opposing, or even counter viewpoints is respected and may be freely offered. Moreover, in focus group interviews, it is more difficult to maintain the confidentiality of a participant's responses as a result of having other participants in the room. Therefore, in choosing to use focus group interviews, one must also carefully consider the sensitivity of the issues being discussed.

Despite some of the additional considerations for the use of focus group interviews, this format also provides a number of potential benefits with respect to collecting rich data. This format may allow participants who are more reluctant in an individual interview to feel more willing, and encouraged, to respond within the group setting. Hearing others' ideas, too, may prompt one's own thinking and add to the multiple perspectives desired from this type of interview. For example, focus group interviews were used in the CER study by Stojanovska et al. (*13*) to examine misconceptions students held about the

particulate nature of matter. In particular, the researchers noted that having students interact and exchange ideas during focus group interviews provided valuable information about misconceptions and source material for follow-up questions.

Think-Aloud Interviews

Think-aloud interviews differ from open-ended interviews in that they ask participants to articulate their thoughts during a specific task or when solving a particular problem. Bowen (*14*) essentially describes this method as a way to listen to learners. It is less focused on broader feelings or perceptions of a course or an instructional approach, and more focused on a participant's reasoning during pre-selected tasks. Think-aloud protocols are often selected when a researcher wants to know how or why a participant is using knowledge, processes, algorithms, or heuristics to solve problems or complete tasks. These verbal data help researchers make inferences about what information is focused on in a problem and what processes are selected when solving the problem.

When using think-aloud interviews, the selected problem itself becomes the source material for the interview "questions". The participant usually does most of the talking, describing his or her thoughts and reasoning during the solving of the problem. Other prompts or follow-up questions may be used after the problem is solved. These follow-up questions, though, ask participants questions from a slightly different vantage point. During the problem solving, participants are likely providing descriptions from introspection – what they are actually thinking during problem solving. Descriptions provided after solving the problem come more from retrospection, which is reflecting on the problem solution and why they solved the problem the way they did (*14, 15*). Both question pathways, during or after problem solving, may provide relevant information for the research framework, but are different avenues of knowledge accessed by the participants and should be treated as such during analysis. Ultimately, think-aloud protocols can serve as a way to uncover knowledge and the mental models participants activate with a particular term, concept, or type of problem (*10*).

In the think aloud study (*2*) highlighted in Table I, the researchers asked graduate students to think-aloud while solving complex organic synthesis mechanisms. The ultimate goal of this research was to determine how prior experiences (such as, undergraduate courses) may or may not have prepared students for novel organic chemistry problems they encounter in their own graduate research. The think-aloud interviews allowed researchers to see how students used the curved-arrow or electron-pushing conventions typically taught in undergraduate organic courses. Participants described their reasoning concerning what the arrows actually designated and why they used a particular

set of steps in the solution. Other CER studies have used think-aloud protocols to investigate students' thinking when solving algorithmic and conceptual chemistry problems (*16*), to assess chemistry teachers' understanding of chemical equilibrium (*17*), and to describe students' use and connections made among different representations of matter (*18*).

Developing the Interview Protocol

Identifying the Desired Information before Starting the Interview Process

Interview participants provide valuable gifts, i.e.their time and insights. Therefore, it is important that the information the researcher wants to obtain from the interview is framed prior to starting the interview process. This process should be shaped by the theoretical framework, research questions, and hypotheses of the study. Even if the investigation is purely exploratory, the topic of interest should be carefully considered so that questions can optimize collection of the desired data. In their "Seven Stages of an Interview Inquiry," Kvale and Brinkman (*10*) call this stage "thematizing" - identifying the why and what before the how. For a structured interview this means identifying important topics to discuss during the interview so that an appropriate set of questions can be developed for the interview protocol. For example, in exploring how students integrate their scientific knowledge, Taber (*1*) (Table I) made a choice based on the research question. In order to determine how students integrated knowledge across chemistry and physics content areas, Taber reasoned that, "collecting data about thinking over a range of topics was more important than being able to spend time approaching particular topics from a range of perspectives." As a result, he used prior research to identify a series of topics that students should be able to integrate across chemistry and physics, and developed questions for an interview protocol based on those topics.

Within a think-aloud protocol, preparing for interviews could mean considering the tasks or problems to be used during the interviews, what the variables are, and why anticipated answers to those problems and students' descriptions of their reasoning would be relevant to addressing the research questions (*14*). For instance, Bhattacharayya and Bodner (*2*) situated their research within a phenomenographic framework. They chose a think-aloud interview because it would give a voice to the participants by making the students' underlying thought processes explicit, thus providing the researchers an opportunity to uncover and to interpret student strategies. Though the researchers anticipated "multiple voices," they hypothesized that there would be a finite number of differing approaches, which would allow them to characterize a finite set of problem solving strategies.

In addition to determining the type of information desired from an interview, researchers must also carefully consider the interview format. For instance, if a researcher is interested in students' perceptions of learning with a particular instructional approach, a focus group interview might seem to be a good format for obtaining multiple and varied viewpoints about these perceptions. In using this format, though, confidentiality has to be protected as much as possible. Comments shared by individual participants should not be shared with the professors who are using the instructional approach being studied. Instead, comments need to be compiled and not be attributable to individual students in the class. Ethical considerations must be simultaneously at the forefront in the thematizing stage as well as evident throughout the interview inquiries. To assist the researcher with this, guidelines for working with human subjects have been established and should be followed throughout the research project. Additional descriptions and guidelines for conducting research with human subjects are described in this volume by Bauer (*19*).

How to Construct Good Interview Questions

The questions asked in an interview ultimately depend on the focus of the study, but there are some guidelines to keep in mind when writing interview questions to help ensure that they furnish valuable data. There are several different types of questions that can be asked. Although there are multiple ways to classify types of interview questions, one useful classification scheme is provided by Patton (*3*). Patton suggests that all interview questions can be classified into one of six different categories, which have been summarized in Table II. Table II also highlights the type of information that each type of question is meant to elicit and provides an example of how each type of question has been used in a CER or science education research study.

Although there is no set way to order interview questions, in general, most interviews start out with Background/Demographic type questions and then move to other types of questions. Both Patton (*3*) and Merriam (*5*) suggest that a good progression is to first ask participants to describe a situation (Experience/Behavior or Knowledge questions) and then follow-up with questions about how they feel about the situation (Feeling or Opinion/Value questions). In our experience, this provides a good model to follow. For example, in studying the Target Inquiry professional development program and its impact on teachers' understanding of inquiry instruction, Herrington et al. (*20*) first asked high school teachers to use a set of cards to construct their model of inquiry-based instruction (Experience/Behavior) and then asked them to explain and justify their model (Opinion/Value).

Table II: Types of Qualitative Interviews Questions

Question Type	*Type of Information Provided*	*Example in CER*
Background/ Demographic	Used to identify characteristics of a person or program (age, chemistry courses taken, major, years of teaching experience, number of students, etc.).	*How many faculty teach the lecture portion of this course? Are they all tenured or tenure-track? (how many tenured, tenure-track, and/or contract?)* (*21*)
Experience/ Behavior	Used to elicit information about experience or behaviors that would be visible if the interviewer were present as an observer.	*How do you study for this course? Describe a typical week.* (*8*)
Opinion/Value	Used to try and understand what a person thinks or the rationale used for a certain action/decision. Used commonly as probes during or after think-aloud interview protocols (Can you explain why you chose to use that method?)	*Which labs were most helpful in learning the lecture material? Why?* (*7*)
Feeling	Used to identify a participant's emotions.	*How do you feel about science subjects at your school*? (*22*)
Knowledge	Used to determine a person's factual knowledge.	*I dissolve lead sulfate in water to form lead ions and sulfate ions. What will happen if I add solid lead sulfate to this? It is at equilibrium initially.* (*23)*
Sensory	Used to identify sensory inputs (sight, sound, taste, smell, and touch) experiences in a situation.	*Which tactile representations of images did you find to be helpful / not helpful and why?* (*6*)

Another key consideration is how to word (or phrase) the questions. First, it is important that the questions are clear to the person being interviewed. Using obscure terms or disciplinary jargon should be avoided. Second, if participants feel uncomfortable answering a question, it is unlikely that they will provide useful data. If asking a somewhat controversial or personal question, it may be helpful to pose it in a way that takes the direct focus off of the participant. Some examples include asking a hypothetical question, playing Devil's advocate (Some people might say…), or asking about an ideal situation (*5*). For example, asking students what they thought about the feedback they received on assignments in their chemistry class may not yield completely honest answers if students are concerned that their responses might get back to their instructor. However, rewording the question and asking "If you were teaching this course, what kind of feedback would you give students on their assignments?" may allow students to voice opinions about things they felt were lacking from the feedback without worrying about giving a negative response about their instructor.

Finally, there are some things that researchers should take care to avoid when crafting interview questions. Asking multiple questions at once is problematic. For example, "How would you assess your learning and effort in CHM 100?" is a poor question because learning and effort are two separate things. If the researcher is interested in students' assessments of both learning and effort, each of these should be asked separately. This separation will also facilitate analysis of the interview data. In general, yes or no questions should also be avoided as they do not yield the rich, descriptive data desired from a qualitative interview. For example, if investigating the structural features of molecules that students focus on when making predictions about chemical reactions, consider the following ways of asking the same question:

(1) Are there any structural features of the molecule that you looked at in deciding what type of reaction would occur?
(2) What specific structural features of the molecule did you look at in deciding what type of reaction would occur?

The first question students can answer with a yes or no. Of course this could be followed up with "which ones?" but this can lead to a back and forth that is more like an inquisition than an interview. The second question, on the other hand, prompts students to identify the structural features without the need for a follow-up. There are, however, some cases where yes or no questions can be appropriate and useful. For example, in the Taber study (*1*) highlighted in Table I, several yes or no questions were used in the interview protocol. In some cases a yes or no question was used to determine whether a student was familiar with a particular phenomenon , such as a balloon sticking to a wall after being rubbed on a sweater, before asking follow-up questions about the phenomenon.

In others, a yes or no question was asked first to determine whether a student thought a particular thing was possible (e.g., *Do you think a single sodium atom can fall apart?*), and then it was followed up with a why/why not question to elicit the student's rationale.

Perhaps the most important and most difficult pitfall to avoid is using leading questions. At first glance a question such as "What did you like about CHM 100?" may seem like a good open-ended question, yet, it carries with it the implicit assumption that the class was good. Another way to approach this is to say, "Tell me what you thought about CHM 100." This invites the participant to discuss both the positives and negatives of the course.

One final caution about interview questions is using why questions. Although a well-placed "why do you think that" can provide valuable insights, why questions can also hinder the collection of meaningful data (*3*). When asking a participant why he or she answered a question in a particular way, the interviewee may feel that the answer was somehow inappropriate or inadequate. Simply rephrasing the question as, "Can you tell me more about your thought process in answering that question?" may be more inviting. Furthermore, in some cases there are many reasons "why" a person might choose to do something that could include personal choice, level of understanding of the topic or content, desire to please the interviewer, etc. A participant may not be able to distinguish among these reasons and clearly articulate which one explains his or her answer. In this case, if a researcher is particularly interested in one thing, such as a feature of the question that prompted a particular response,then more useful data may be obtained from rewording the question. For example, it may be more useful to ask, "Can you tell me what features of the question resulted in you choosing that problem solving method?" as opposed to asking, "Why did you solve the problem that way?"

How to Construct Good Tasks for Think-Aloud Protocols

Considerations for think-aloud interviews are somewhat different from constructing good open-ended questions because participants are describing their thought processes as they complete pre-designed tasks. In think-aloud protocols, the goal is to have the participant describe what he or she is thinking while completing the task without any interruptions or prompting questions. This makes the development of the tasks very important. Though the specific tasks will differ based on the research question, there are several things to consider when choosing appropriate tasks. First, the tasks have to be problems that participants cannot solve automatically, avoiding situations where a participant may be able to get the correct answer without actually being able to describe how it was determined(*15)*. For example, students may be able to draw a Lewis structure for CO_2 from memory without the need to think about how to

draw it. On the other hand, tasks should not be too unusual. If a participant does not know where to start, he or she will probably not be able to provide useful interview data. For example, in Bhattacharyya and Bodner's study of organic mechanisms (*2*), they used problems that required 2-4 step mechanisms, many of which were found in standard undergraduate organic chemistry textbooks. Using resources such as textbooks to generate a pool of items for selecting appropriate tasks for developing think-aloud protocols is a good strategy (*14)*.

The time required for participants to complete the task is also an important consideration. In a study looking at concept learning versus problem solving, Nakhleh and Mitchell (*16*) asked students to solve one conceptual and one algorithmic gas law problem from their recent exam as well as a pair of stoichiometry problems using the think-aloud method. Each interview took approximately 50 minutes. This illustrates that it is important to recognize that think-aloud protocols are typically limited to just a few problems, because thinking aloud while solving problems generally requires more time than just completing the task alone. Sessions that are too long can lead to participant fatigue, which in turn can affect the quality of the data obtained.

Another consideration in developing think-aloud tasks is what resources will be provided to participants (periodic table, calculator, textbooks, molecular models, etc.) (*14*). For example, in the Bhattacharyya and Bodner study (*2*), they provided their participants with two different comprehensive organic textbooks and a set of molecular model kits. These resources allowed students to envision the 3D structure of a molecule or look up information (e.g., pKa, the purpose of a particular reagent, or the reactivity of a particular functional group) important in determining the reaction mechanism, thus eliminating student content knowledge as a confounding variable in their study of organic problem solving.

Piloting the Interview Protocol

The importance of piloting the interview protocol cannot be stressed enough. One way to pilot an interview protocol is to practice with someone who is familiar with using interviews as a tool in educational research as he or she will likely be able to provide valuable feedback about the interview questions and give some insight on how to deal with other issues that could be encountered in the interviews (e.g., the reluctant participant, the participant who has difficulty answering the question you asked, etc.). However, it is also important to conduct a few pilot interviews with the target population for the study. This is the fastest way to figure out which questions are confusing to the participants, which questions elicit unanticipated responses, and which questions do not provide meaningful data and thus need to be reworded or eliminated from the protocol. Furthermore, participant responses from pilot interviews may

suggest questions that are missing from the protocol that should be included or probes for certain questions that could be used with participants who are less forthcoming with information. For example, in the study of the Target Inquiry program (*20*), after the first year of the program teachers were asked to describe any changes to their teaching during the preceding year. Several teachers also mentioned changes they had noticed in their students as a result of changes to their teaching. Thus, a follow-up probe was added to the interview protocol (*Have you noticed any changes in your students? If yes, can you describe those changes?*) as a prompt for teachers who did not volunteer information about students in their initial response. Additionally, for participants who were less forthcoming with information, additional follow-up prompts (*Prompts: What about student motivation? Retention of information? Understanding of concepts? Student frustration?*) corresponding to the things teachers most frequently mentioned in relation to changes in their students were included. In McClary and Talanquer's study of student models of acid and base strength (*24)*, piloting their interview protocol indicated that asking students to justify all of the acid strength ranking tasks took too long and resulted in cognitive overload. Thus, the researchers modified their protocol so that students only justified the three most complex ranking tasks.

The use of a think-aloud protocol is somewhat different, but it is still important to pilot this interview protocol. Doing so will help determine whether the tasks are serving their purpose. Moreover, when using a think-aloud protocol, it is important to practice the think-aloud procedure with each of the participants in a warm up activity as this process is often unfamiliar to them. In the study by Nakhleh and Mitchell (*16)*, the researcher trained the students by first demonstrating the think-aloud method himself as he completed a practice problem and then had each participant complete a practice problem using the think-aloud method. More often, however, researchers provide participants with instructions regarding the think-aloud procedure and then give them a practice problem that allows them to try using the think-aloud method.

Selecting Participants

Using interviews for data collection allows the researcher to investigate selected issues or concepts in great depth, but this is only possible with participants who provide information-rich cases to study. Unlike quantitative methods which rely on random sampling to provide the most robust generalizations of statistical comparisons to the larger population, obtaining quality data from interviews requires more purposeful sampling. Although most often interview participants are volunteers, choosing appropriate volunteers is important. For example, in Taber's study looking at conceptual integration across topics in chemistry and physics (*1*), he chose students working at an

advanced level, who had shown interest in science, had studied both chemistry and physics at a college level, and had been academically successful because, "These are students where we might expect significant evidence of conceptual integration, and who should cope with the challenge of a broad-based interview of around an hour's duration."

Often in CER, researchers may find themselves recruiting participants from a convenient source such as a particular section of a general chemistry lab or lecture. This is known as convenience sampling and for many research studies may be perfectly appropriate. Other times it is important to ensure recruitment of participants with adequate variation across a variable of interest (e.g., low, medium, and high performing students), known as maximum variation sampling. An example of this can be found in the study by Cole and Todd (8). In this study they used the Group Assessment of Logical Thinking (GALT) as a pre-test measure because it has been shown to correlate well with performance in general chemistry. Students in their study were divided into four groups based on their GALT scores (high or low) and homework type (online or textbook). The researchers then randomly selected six students from each of the four groups to participate in interviews. Ensuring participation from each group provided researchers with the opportunity to determine whether a particular homework type was more favored by a particular group of students.

Another example of purposeful sampling methods for conducting interviews can be found in the study by Bruck, Towns, and Bretz (*25*). The aim of this study was to identify the goals, strategies, and assessments used by faculty members involved in the development and implementation of laboratory curricula at American Chemical Society (ACS)-approved institutions. In particular, the researchers were interested in investigating the relationships between faculty goals and (1) institution type, (2) course level taught, and (3) whether the faculty members had received National Science Foundation Course, Curriculum, and Laboratory Improvement (NSF-CCLI) funding to improve laboratory instruction. Thus, the researchers purposefully identified faculty who had received NSF-CCLI funding and those who had not and then used stratified random sampling across institution type and course level taught to select faculty to invite to participate in interviews. These are just a few different strategies for purposeful sampling. Patton (*3*) describes 15 different purposeful sampling strategies.

Related to choosing participants for interviews is the issue of sample size. Unlike quantitative methods where certain sample sizes are required to provide adequate power to detect significant changes or differences, there is no set required number of interviews for a study. In an ideal situation where timelines and resources are plentiful, Lincoln and Guba (*26*) recommend that the sample size be dictated by saturation. Saturation means that data are collected until no new information is gleaned from sample units. In practice, saturation rarely occurs and thus the decisions about sample size are largely tied to the

goals of the study along with the time and resources available to the researchers. In some cases, in-depth information from a small number of people (even N=1) can be very valuable. In Taber's study on conceptual integration (*1*), four students were interviewed, but in order to illustrate the value of a broad research protocol in obtaining meaningful data, he chose to describe the findings from just one of those interviews in detail as a case study. In other cases, where researchers are looking to identify patterns or variations across a phenomenon, it is often necessary to interview a larger number of participants in less depth. For example, by interviewing 14 participants (25% of the class) Bhattacharyya and Bodner were able to identify patterns in the use of curved arrow notation that were consistent across several of the participants (*2*).

Conducting the Interview

Developing a Rapport

Getting good data from interview participants often depends largely on the interviewer's ability to develop a rapport and make the participants feel at ease. Two very important things to consider in relation to this are (i) the location of the interview and (ii) who will conduct the interview. It is important that interviews are conducted in a neutral location where it is possible to ensure that other people will not be able to hear the interview or walk in during the interview. This suggests that holding interviews in a faculty office is not typically a good choice, especially when interviewing students, as this could set up a power dynamic that could make students feel uncomfortable.

To develop a rapport with participants it is important to remain respectful and sensitive to the participant while at the same time remaining neutral and non-judgmental. This is often difficult as researchers have their own biases. However, it is critical that the participants feel that they can share honest responses with the researcher without being judged. This is also difficult to do if there is a power dynamic, either real or perceived, between the interviewer and interviewee, such as that between a professor and a student. For CER studies that involve interviewing students, one option, although not always possible, is to have students conduct the interviews. Students typically feel most comfortable talking to other students whom they do not view as being more knowledgeable than they are and are less likely to judge them if they do not know "the" answer to a question. Another good strategy, again if possible, is to develop a rapport with participants before the interview. This importance of rapport has been underscored in the work that we (the chapter authors) have done with teachers. Working with teachers in an environment where they have perceived that their ideas and input are valued and where they have been treated

as colleagues has allowed us to gain their confidence and trust. Such trust has resulted in fruitful interviews.

Paying Attention during the Interview

Paying attention during an interview is not only an act of respect to the participant, but can also help a researcher maintain control of the interview. If the researcher pays close attention to participant responses, he or she is better prepared to redirect the participant who is not answering the question asked or who may be meandering in his or her responses. Time for both the researcher and participant is a precious commodity and thus it is imperative to use that time to get as much useful data as possible. If a participant goes off topic, the researcher should find an opportunity to interject and redirect the participant. A couple of examples of how a researcher might do this are:

- I would like to focus back on the difficulty you described having with equilibrium problems.
- That is very important, but I am most interested in how you actually solved the equilibrium problems. Could you tell me specifically about the approach you took to problem #5?

This will also help address participant fatigue as it will prevent the interview from becoming too long. Interviews lasting less than an hour for secondary and post-secondary students are common and typically do not result in participant fatigue. If interviews need to be longer, then appropriate breaks for the participant when fatigue is observed can be beneficial to data collection. Finally, paying attention provides opportunities for the researcher to probe more deeply into responses, particularly if the responses appear superficial.

Giving Participants Appropriate Feedback and Support

Something that will help build a rapport with participants and ensure continued collection of useful data throughout the interview is being sure to give participants appropriate feedback and support along the way. Remaining neutral is important, but that does not preclude the researcher from letting participants know that their contributions are valued or providing them with encouragement and feedback. For example, telling participants that their honest feedback about the homework in CHM 100 is appreciated because it will be valuable in helping improve the course can make the participants feel valued and encourage them to provide additional details. Moreover, simple phrases like the following are good ways to encourage participants to keep going if they appear to be tiring.

- A number of students struggle with that question.
- I understand how that can be challenging.
- That is great. That is exactly what we are looking for.
- Okay, I just have a couple more questions for you.

Patton provides numerous other examples of ways to rephrase questions, transition from one topic to another, or to give participants supportive feedback that researchers may want to consider, in particular if they are planning to conduct longer interviews (*3*).

Recording interview data

Recording the interview is ideal as it frees the researcher from taking copious notes and allows him or her to pay attention to the participant responses. Recording, though, brings with it ethical considerations concerning the ability to maintain confidentiality of participants (see also the chapter by Bauer (*19)* in this volume). This is especially true when deciding whether to use audio only or audio and video recordings. Video recordings have the benefit of capturing participants' expressions and mannerisms, the non-verbal cues, during an interview. Such features may inform aspects of the research. Video recording devices, though, can be more difficult to set up (angles, positioning, lighting, etc.) and participants may be more tentative with both video and audio recording over audio only. Technology advances (e.g. mobile devices with applications), though, have facilitated both forms of recordings and lessened the intrusion of recording during the interview process.

Ultimately, because interviews are about gathering information from human beings, the comfort level of the participant is important. If participants are hesitant about having their comments, expressions, or actions recorded, the data can be skewed or biased. Frequently, any slight hesitation or nervousness participants may have with being recorded fades if the interview has a comfortable flow. This is one reason why starting with more demographic or knowledge types of questions and developing a rapport with participants is so important. However, it is still important to give participants the option of having the recording stopped at any time. If the recording device continues to make a participant uncomfortable, then an researcher should turn it off completely and just take notes.

Regardless of the use of recording devices to capture an interview, a researcher may still want to take notes during an interview. The first reason being that the audio recording may fail and the notes might be the only data source from an interview. More importantly, however, is to record initial

impressions, indicate a comment for follow-up, or underscore a phrase or term that, within the moment, appeared relevant.

Interviews for the purpose of data collection are often single shot opportunities. There is rarely a chance for multiple trials with the same sample. Even if a researcher is able for some reason to conduct an interview again with the same participant, the questions have already been asked, and so the participant's responses, even during an immediate redo of the interview, may change somewhat because the participant has already heard the interview questions. Therefore, it is critical, prior to conducting interviews, to test the devices to make sure they are functioning appropriately and placed properly to capture varying volume levels. This testing step can be combined with the steps for piloting the interview protocol that were described earlier. Finally, establishing a consistent template for saving recorded data is crucial. The form of the recording (e.g. file type), what was recorded, from whom, when, how the files are named and stored, paying particular attention to maintaining confidentiality, are small but critical details when using interviews as a research tool.

Media for Conducting Interviews

Most researchers would probably prefer to conduct interviews face-to-face because it is easier to build a rapport with participants and it provides researchers the benefit of non-verbal cues that can signal the asking of follow-up questions. However, distance and incompatible schedules between researcher and participants can make conducting face-to-face interviews difficult and sometimes more costly. Thus, researchers have looked to other formats for conducting interviews including: (1) phone; (2) email; and (3) video-chat. Given the increased use of these virtual forms of communication, alternate interview formats are likely to become more common. All of these methods provide the benefit of giving the researcher access to participants over a greater geographic area for a relatively small cost as compared to conducting face-to-face interviews with the same participants, but each of these methods also has several other inherent pros and cons. The following sections discuss the use of each of these methods for conducting interviews with some of the most notable pros and cons for each of these methods summarized in Table III.

Table III: Pros and Cons of Using Media for Conducting Interviews

	Phone	*Email*	*Video-chat*
Cost	Relatively inexpensive	Relatively inexpensive if	Relatively inexpensive if participants have

		participants have reliable access	computers, webcams, and software
Participant access/ Scheduling	Can access participants across great geographical distance without travel but still requires compatible schedule	Researchers can send out questions to multiple participants at the same time and participants can respond when convenient	Can access participants across great geographical distance without travel but requires compatible schedule
Verbal and non-verbal cues	Access to verbal cues but not non-verbal cues	No access to verbal or non-verbal cues	Access to both verbal and non-verbal cues
Data processing	Requires reliable means of recording audio. Interviews need to be transcribed	Data is already in typed format, no need to transcribe	Requires reliable means of recording video and audio. Interviews need to be transcribed

Phone Interviews

Phone interviews have become very popular with market research where typically very structured interview protocols are employed. This type of interview has generally been considered less desirable for less structured qualitative interviews because of the absence of non-verbal cues to help direct the interview. More recently, however, phone interviews have been used in qualitative studies (*27, 28*). In Irvine's comparison of phone and face-to-face interviews (*28*) she found that (i) on average participants in phone interviews talked for a shorter amount of time and provided less detail and elaboration than participants in face-to-face interviews, and (ii) the interviewer did a larger portion of the talking in phone interviews. Additionally, phone interviews, like face-to-face interviews, require recording and transcribing, thus it is important to have a good quality audio recorder that can capture the phone conversation. While these are certainly limitations of phone interviews, Holt (*27*) notes several advantages to phone interviews in addition to increased access to participants. Phone interviews provide an added sense of anonymity, which can result in participants being more open about sensitive or personal topics. Furthermore, she notes that phone interviews can serve to eliminate perceived power differences between the researcher and participant that can make it difficult to develop a rapport with the participant.

Email Interviews

Unlike face-to-face, phone, or video-chat interviews, email interviews lack verbal cues that can help the researcher assess the comfort of the participant and reliability of the responses. Additionally, email interviews are asynchronous. The advantage of this is that participants can take their time and think about their answers. This generally results in more thoughtful answers as well as fewer fragmented sentences than synchronous methods (*29, 30*). Other advantages include (1) the ease of scheduling as there is no need to find a time that works for both researcher and participant, rather a set of questions can be sent out to several participants at once; and (2) eliminating the need for transcription of the data as it is already in text form. On the other hand, the time it takes for data collection may be extended because it depends on how quickly the participants respond to the initial questions and the follow-up questions. Several researchers have also found that participant attrition is higher with email interviews than with other synchronous forms of interviews as participants can drop out at multiple points (after the initial invitation, after the initial set of questions, or after any set of follow-up questions) (*30, 31*). Finally, there are also concerns with email interviews about the reliability of the data as it is not possible to verify the identity of the person who is actually providing the information (*29*).

Video-chat

The increased use of video conferencing software, such as Skype, provides another option for conducting interviews that carries with it similar advantages of other methods while still providing the researcher with valuable verbal and non-verbal cues. Hanna (*32*) also suggests that for some participants, being able to take part in the interview from the comfort of their own homes may be advantageous. If the participant is in a comfortable environment, then he or she is likely to be more open and honest with responses.

Like face-to-face and phone interviews, Skype interviews still need to be recorded and transcribed. A quick internet search will provide a list of software programs, some that are free access and some that have fees, that can be downloaded and used to record both the video and audio portions of a Skype call. The ability to capture video data in the interview can provide an additional data source for researchers to analyze.

Other Media for Interviews

There are some types of interviews that do not lend themselves well to formats other than face-to-face. For example, in think-aloud interviews, in addition to collecting verbal data regarding participants' thought processes, researchers also observe what participants are writing and collect any artifacts they construct. These verbal and observational data are still best collected simultaneously using face-to-face methods. Nonetheless, there are some forms of technology and programs that can be used to capture students' drawing and monitor their progress as they work through problems.

For example, in a study of students understanding of enzyme-substrate interactions, Linenberger and Bretz (*33*) report the use of the Livescribe digital pen to capture the audio of students' explanations overlaid upon digital images of what they have drawn. This technology is finding more use in CER studies as it overcomes several data analysis difficulties. In particular, Linenberger and Bretz reported that even with videotaped interviews that included audio and copies of student drawings, they often had difficulty interpreting student drawings given that students made several markings on the same drawing. The Livescribe pen, however, ties the audio to the specific pen marks students make, thus eliminating this analysis challenge. Another excellent description of the use of technology to collect and analyze data in CER studies is provided in this volume by Cooper, Underwood, Bryfczynski, and Klymkowsky (*34*).

Analyzing the Interview Data

Transcription

If interviews are recorded, then the first step in analyzing the data is usually transcribing the audio portion of the recordings. Good transcription, which includes line numbers in the document for referencing, takes time, and if using a professional service, can be costly. Industry Production Standards suggest that one hour of interview recording takes about four hours to transcribe (*35*). Merriam (*36*) describes two options for transcribing: verbatim or interview logs. Verbatim transcription captures every word, utterance, and sound from the interview. Interview logs are a process for capturing the main points. Though interview logs may be a more affordable alternative to verbatim transcription, the ways to measure their reliability is not entirely clear.

Ideally transcription is done without bias. However, unbiased transcription is often not possible. For example, what does it mean to transcribe an interview verbatim? Was the sound a laugh or a sigh? Is there any way to capture voice intonation or inflections? What about grammar and punctuation?

Does punctuation change the interview data? For instance, consider the same audio recording transcribed in the following two ways:

- "Organic reaction mechanisms are tough, you know. I really think so,"
- "Organic reaction mechanisms are tough. You know I really think so"

Would those two transcripts lead to slightly different interpretations of data? Such considerations are important in moving to data interpretation (*37*). Even though transcription itself may be a slight first level of data interpretation, it remains the best preparation of recorded interviews for analysis, especially when done with as little bias as possible. Though this process is time consuming, accurate transcriptions can facilitate rich analysis of the interview data.

Importance of a Theoretical Framework

Maxwell (*38*) defines a theoretical framework as "the system of concepts, assumptions, expectation, beliefs, and theories that supports and informs your research." The driving question(s) of a research study and how that question is asked is a reflection of the theoretical framework or theoretical orientation behind the study. Different theoretical perspectives allow researchers to look at the same situation or same data and ask different questions or focus on different elements of the data. Merriam (*5*) gives the example of an educator, sociologist, and psychologist looking at the same classroom. The educator may ask questions about instructional strategies, the sociologist about social interaction patterns, and a psychologist about motivation. In analyzing interview data, the theoretical framework provides the lens through which the researcher views the data. For example, in the Bhattacharyya & Bodner study highlighted in Table I (*2*), the researchers had phenomenography as their theoretical orientation. The authors chose this theoretical framework as they were looking to identify and classify the different strategies students used for solving complex organic mechanistic problems. The phenomenographic perspective presumes that people experience the same phenomena differently; however, the number of different ways people experience a given phenomenon is finite.

A more detailed theoretical framework was employed in a study that looked at how students and faculty connect levels of representation (macroscopic, particulate, and symbolic) (*18*). The authors used a "levels of complexity" framework which allowed them to classify participants' explanations of phenomena as emergent (macro-level properties resulting from a particulate level mechanism) or submergent (imposing the properties of the macro-system on the particulate). Thus, in the analysis of the interview data, the researchers were looking for how participants were making connections between

the two levels. They provided the following examples of emergent and submergent explanations.

> **Emergent: "***Let's say the gas is comprised of particles; the particles collide with the walls; the collision with the walls creates pressure. […] The moment I looked at the diagrams, I immediately thought 'particulate model'. According to this approach, it should be divided to the smallest particles that are still relevant to the problem. In this case, the fact that we have H_2 is not relevant. The molecular structure of the gas does not change at all. Therefore we can simplify H_2 to be a sphere, a particle, does not matter what. Then I asked myself: which particulate theory is relevant to the problem? We can use a theory of motion, a basic mechanistic theory (John, faculty – Theoretical Chemistry).*"
>
> **Submergent**: In asking a student to describe how the distribution of gas particles would change if the temperature was lowered, the student responded "*OK, I'll go with (b) [gas particles are concentrated in the middle of the tank], since the product PV should decrease, because you lowered the temperature, and P remains the same.*" The researchers explain that this is submergent reasoning as "*in his answer, he first considers the ideal gas equation, and gets to the (incorrect) conclusion that the volume of the gas should decrease. This in turn leads him to impose this conclusion on the submicro representation, and consider the particles as concentrated in a smaller volume.*"

In general, in qualitative research the theoretical framework should guide the research question, the data collection methods, and the data analysis methods. Although a thorough discussion of theoretical frameworks is beyond the scope of this chapter, Patton (*3*) provides detailed descriptions of a number of different theoretical orientations along with the types of overarching questions that characterize each perspective, and Merriam (*5*) provides a clear and concise explanation of how to identify a theoretical framework. Bodner and Orgill (*39*) also provide good descriptions of theoretical frameworks in CER.

Qualitative Coding of Interview Data

The pages of transcription data for interviews might appear daunting and the actual number of pages per hour of interview varies somewhat with the

interviewee. However, with a theoretical framework guiding the conceptualization of coding, some key steps can facilitate this process. Essentially, coding helps construct and verify patterns and trends within the interview data. Approaches to coding can allow the codes to emerge directly from the data, as with a grounded theory approach, or be framed more by an analytic framework in which concepts for codes may be pre-established (*40)*. For example, consider a researcher interested in how students approach drawing Lewis structures. Since protocols exist for drawing Lewis structures, categories for coding students' solutions can be preconceived (e.g., the use of a connect-the-dots approach of one atom's valence electrons to another atom's valence electrons, or an electron summation and redistribution across bonding atoms approach).

Qualitative research experts may have some variations in their described approaches to coding analysis (*5, 36, 40, 41)*, but one approach that captures many common elements is:

1. Go to the data. Get a sense of the whole. Read all transcriptions carefully. Jot down ideas as they come to mind.

2. Pick one transcript and go through it. Do not think about the substance of its information, but focus on its underlying meaning. Take notes on your thoughts. Do this for a few transcripts.

3. Between steps one and two, a list of topics may be emerging, with the possibility of beginning to cluster topics together. At this point, software or application-assisted analysis can facilitate the next steps (see Talanquer's chapter in this volume (42) on strategies for analyzing qualitative data with qualitative analysis software).

4. Go back to the data. Try out the clusters as a preliminary organizing scheme. Consider how well the clusters hold together. Tag transcription statements that relate to initial codes. Pay attention to possible new categories or codes that emerge.

5. Go back to the data and tagged statements. Find the most descriptive wording for these topics and turn them into categories. Look for ways to reduce the list of categories by grouping topics that relate to one another.

6. Go back to the data. Assess how well the categories are holding. Make a final decision on each category and organize these as codes.

7. Go back to the data. Analyze with the developed coding scheme.

In this volume, the chapter by Talanquer (*42*) provides a more detailed description of the coding process with particular considerations in CER and the use of qualitative analysis software.

Triangulation

Just as organic chemists use multiple methods (NMR, IR, GC-MS) to determine the identity of a compound, interview data is often most powerful when it is used in concert with other data to help address aspects of the how and why within the research project. In educational research, this is often referred to as triangulation. Triangulation of interview data with other data sources supports robust data interpretation.

Although good planning for interviews (good questions, timing, setting, developing a rapport, etc.) attempts to ensure quality data are obtained, there are other elements (fatigue, a poor mood, or even an ulterior motive in a respondent) that may compromise the data (*36)*. Checking accuracy with other collected data as much as possible is critical. For example, in reaching their conclusion that organic chemistry students can provide correct answers to mechanism problems despite lacking an understanding of the chemical concepts behind their responses, Bhattacharyya and Bonder (*2*) compared responses to think-aloud interviews with students' actual solutions to organic problems and course grades.

Additionally, the combined use of different research tools described in this book and in chapters in its companion volume (*43, 44*) can provide a means for triangulation of interview data. Consider, for example, students being interviewed about their experience with a particular instructional approach used in their chemistry class. The use of classroom observations in conjunction with interviews can provide opportunities to check for data alignment (Yezierski provides an excellent review of the use of classroom observation protocols in this volume (*45*)). Alternatively, in using a think-aloud protocol during the solving of selected problems, a researcher may also choose to use an eye-tracking device as measure of how participants read the text of the problem or examine any structures provided (in this volume Havanki and VandenPlas discuss the different ways eye tracking technology can be used in CER (*46*)).

Using interviews within a research design must involve an acknowledgement that interpretation is part of nearly every stage of the process and additional data sources can improve validity and reliability of the study findings. Alone, interview data do not always provide enough evidence for making robust conclusions. These data, though, within a set of convergent measures can make powerful contributions to the research story.

Summary

The interview is a tool that provides a valuable means for researchers investigating "how" and "why" questions and allows access to the "unseen," namely participants' thoughts, beliefs, and feelings. When guided by a clear theoretical framework and a well designed protocol, interviews can provide rich data about participants' experiences, knowledge, and practices. With careful planning at all stages of development, implementation, and analysis, interview data can act as valuable data sources in CER studies.

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