Construction of an Instructional Design Model for Undergraduate Chemistry Laboratory Design: A Delphi Approach

by

Tara Bunag

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Graduate Supervisory Committee:

Wilhelmina Savenye, Chair
James Klein
Joseph Springer

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ABSTRACT

The purpose of this study was to construct an instructional systems design model for chemistry teaching laboratories at the undergraduate level to accurately depict the current practices of design experts. This required identifying the variables considered during design, prioritizing and ordering these variables, and constructing a model. Experts were identified by multiple publications in the Journal of Chemical Education on undergraduate laboratories. Twelve of these individuals participated in three rounds of Delphi surveys. An initial literature review was used to construct the first survey, which established the variables of design. The second and third surveys were constructed based on the answers from the previous survey and literature review. The second survey determined the priority and order of the variables, and the third survey allowed the participating experts to evaluate the preliminary design model. The results were validated by interviewing three additional experts who had not participated in the surveys. The first round survey produced 47 variable themes identified by the experts as being important to chemistry laboratory design. Of these, 46 variable themes were determined to be important based on their responses to the second-round survey. Second-round survey results were used to determine the order in which participants consider the themes, allowing for construction of a preliminary design model. In the third round, participants found the model to be accurate, organized appropriately, easy to understand, and useful. Interviews supported these results. The final design model included five main phases with individual considerations or steps. These five phases were named planning, development, implementation, revision, and evaluation. The first four phases form a cyclic process, and they are supported by the continuous evaluation phase. The strengths of the model developed in this study include the participation of experts within the field, the ability of the model to start discussions regarding design, and the high level of agreement on the final model. This model could be refined and evaluated to determine its efficacy in assisting novice or expert designers in creating and improving experiments that support learning. The method used in this study could be used for model development in other fields.

DEDICATION

This dissertation is dedicated to my family and friends, who all pushed, pulled, and cheered to make this possible.

Thank you to my parents for never doubting in me and always being there, no matter what. Thank you to my grandfather, who showed me the harmony of combining unexpected fields, and to my grandmother, who taught me patience. Thank you to my brother, Ben, for always reminding me that there is more than school and work, and to Jesse, Nikki, and Jimmy, for making me smile.

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INTRODUCTION

The description of chemistry as "the 'central science,'" (Metz, S., 2009, p. 6) and a key "laboratory science" (p.6) highlight the importance of chemistry as a field and the importance of the laboratory specifically. These laboratory experiments vary in style, efficacy, content, and design. There is little research on the appropriate design of chemistry laboratories. This can make it challenging to evaluate comparisons between different types of laboratories and their content.

Instructional materials can be created by an expert in a creative endeavor, or they can be created through a more scientific, systematic approach through the use of instructional design models (Andrews, D.H. & Goodson, L.A., 1980). Andrews and Goodson (1980) note that some of these models lack validation and clear applicability to a specific educational setting, which may explain the sparse application of these models to chemistry laboratory design at the college level. This study combined an investigation of the creative aspects of instructional design as it is carried out by expert chemistry laboratory designers with instructional systems design models from the literature to create a model for chemistry laboratory design that is directly applicable to the field.

Efficacy of Chemistry Laboratories

Lippincott (1969) and Brooks (1970) note the struggles chemical education researchers have experienced in determining whether the chemistry laboratory is an effective teaching method. Chemistry teaching laboratories are included in the curriculum of a variety of institutions, but there has been debate concerning their use throughout the history of the field. As early as 1935, Carmody observed growing doubt in the validity of laboratory work compared to lecture-demonstration, and he attributed this growing doubt to a lack of clear objectives and the lack of appropriate methods for designing and teaching laboratories (Carmody, 1935). Hawkes (2004) highlights research in the field that "showed that laboratory work made no significant difference in tests of information, practical application, scientific attitude, or laboratory performance" to support his position that "chemistry is not a laboratory science" (p. 1257). The chemistry laboratory has been an important part of instruction in chemistry, in spite of the lack of evidence supporting its efficacy in promoting student learning (Lagowski, 1999). Lagowski (1999) adds "there are, of course, a large number of *opinions*," (p. 428) while also noting that "the curriculum should become more laboratory oriented" (p. 431). In the time between Carmody (1935) and Hawkes (2004), there has been extensive research into the components of chemistry teaching labs and types of chemistry labs, but little consensus on the efficacy of laboratories or the methods used to teach them. Studies of laboratory efficacy are complicated by a variety of factors.

One of the challenges of determining the extent to which laboratory work is an effective type of instruction is readability of materials, making it challenging to determine whether students are lacking understanding of the chemistry content or instead are lacking preparation in reading chemistry materials (Wilson & Chalmers-Neubauer, 1988). Wilson and Chalmers-Neubauer (1998) describe four levels of reading comprehension and methods to use to encourage deeper comprehension of the chemistry laboratory materials. Though these authors focus on the necessity of appropriate reading strategies for laboratory manuals, they also highlight an additional concern regarding the design of chemistry laboratory teaching materials. There is little direction in the literature as to how to make materials for chemistry laboratories more easily readable.

There is also a disconnect between students' abilities to perform the mathematics of chemistry and their understanding of the chemistry upon which the mathematics relies (L. Bruck, A. Bruck, & Phelps, 2010). The level of Bloom's taxonomy at which students are expected to perform also fails to match the level at which students are generally taught within laboratory manuals (Airasian, Cruikshank, Mayer, Pintrich, Raths, & Wittrock, 2001; L. Bruck et al., 2010). Students are often taught at a comprehension level in the laboratory, while they are asked to perform at a synthesis level (L. Bruck et al., 2010). Young and Hoffman (1996) and Quackenbush (1985) note the need to sequence instruction to guide students from concrete thought to more complex reasoning, based on the work of Piaget. Piaget (1964) acknowledges a diversity of cognitive development from the concrete to the complex. This highlights the lack of alignment between the level of complexity of the objectives and expectations that is a common challenge in the design of chemistry teaching laboratory experiments. Porter, Smithson, Blank, and Zeidner (2007) note that the alignment of the objectives to the expectations is only beneficial to learning if the objectives are high quality. This highlights the need for agreement on what level and type of objectives could be considered high quality in chemistry. Alignment is challenging in chemistry, where chemists can often disagree on the most appropriate level of the objectives.

Chemistry Laboratory Styles or Types

Most chemistry instruction includes both lecture and laboratory components. Students are instructed using a variety of methods in both these components of instruction. This study focuses on the laboratory classroom-based component of chemistry instruction. The instructional chemistry laboratory typically involves students performing experiments based on provided instructional materials. Students perform the experiments in a laboratory classroom individually or in various-sized groups. Students at the high-school and undergraduate level typically perform experiments that have been extensively tested, though they may also perform novel or less-directed experiments. These experiments may vary widely in type and presentation, though they can be classified into four main styles of laboratory instruction. These different styles further complicate research into the efficacy of laboratory instruction.

"The most popular, and yet the most criticized, style of laboratory instruction is the expository (also termed traditional or verification) style" (Domin, 1999, p. 543). Domin further describes this type of laboratory instruction, in which students are directed to perform a predetermined experiment with a known outcome. Step-by-step instructions are provided by the instructor or included in the instructional materials. When students complete the experiment, they should achieve known, expected results. Both the students and instructors know the expected principles and type of results. These experiments have specific right and wrong answers, and they are mainly used to verify chemistry concepts. The benefit of this type of experimentation is that students are performing the same steps at the same time, making it relatively easy to manage time and chemical resources. Domin (1999) notes the “cookbook nature” (p. 543) of the expository laboratory style. These types of laboratories are efficient, but not necessarily effective. Domin (1999) notes that “analysis of expository laboratory activities as they are currently implemented suggests that virtually no meaningful learning takes place” (p. 544). Lagowski (1999) describes how the expository style fits into the current chemistry course structure:

> Our current model that is supposed to “fit all” consists of (i) classroom lectures in which the students are for the most part passive observers of a (sometimes rapidly) changing subject; (ii) teachers who are expected to be (and who often behave as if they are) the source of all information on the subject; (iii) a course content that is often static to the point that large parts of it are more appropriate to 19th century practices; and (iv) presentation of the subject as homogeneous, with little idea of its relationship to the real world or to other disciplines (p. 431)

Domin (1999) describes another type of laboratory instruction as one that utilizes the “inquiry (or open-inquiry) approach” (p. 544). In this style, students plan out their own experiments, rather than follow predetermined instructions. The benefit of this style is that it encourages higher-level thinking than the expository approach. Pure, open-inquiry is not used as often as the expository style because inquiry laboratories are more difficult to manage and implement effectively. There is no single, right answer in an inquiry laboratory, and students are performing different experimental steps at the same time. It can also be challenging to provide both the appropriate educational and material supports for inquiry laboratories. L. Bruck and Towns (2009) provide further information on the extensive preparation required for both students and faculty in inquiry laboratories, including preparing the students and faculty in the content area and laboratory procedures, and they suggest building up from more direct instruction to inquiry laboratories. The implementation of inquiry laboratories is further limited by the need for extensive faculty or teaching assistant preparations regarding attitudes toward inquiry, and preparing faculty or teaching assistants concerning the methods for teaching this type of laboratory, (Mohrig, Hammond, & Colby, 2007; Roehrig, & Luft, 2004). Brown, Abell, Demir, and Schmidt (2006) note that other types of lab experiments include elements of inquiry laboratories, versus a pure inquiry approach. However the lack of a common definition of "inquiry" can make it difficult to determine how the term is being used to describe a particular experiment or study.

Discovery instruction attempts to be a bridge between expository and inquiry learning, as illustrated by its alternate name of "guided-inquiry" (Domin, 1999, p. 545). Domin describes the details of this style of laboratory instruction. In this type of instruction, students do not know the principle or expected results of the experiment they will perform, since it is typically conducted before instruction on the relevant concept. The instructor does know the expected result and guides students to the result through specific directions. The step-by-step instructions may be the same as in an expository laboratory, but the students do not know what principle they are testing. Alternatively, Merritt, Schneider, and Darlington (1993) modified existing laboratory materials to eliminate part of the instructions provided to the students on how to perform the experiment, but the effectiveness of this approach was not thoroughly evaluated. Cacciatore and Sevian (2009) demonstrated some benefit from the conversion of a single experiment in a course to the guided-inquiry format, though the results are confounded by the inclusion of green chemistry, which includes an awareness of environmental impact of the laboratory, and a lack of detail concerning the design of the original laboratory materials. Cacciatore (2010) further describes the design and theory basis of the design for these green chemistry laboratory materials, using learning theory and sequenced instruction. McKenzie et al. (2009) note the pedagogical benefits of green chemistry exercises, and this benefit confounds the determination of the effects of the guided inquiry approach in the Cacciatore studies. Young and Hoffman (1996) found no difference in achievement with discovery learning, though their study was limited to the application of discovery learning to demonstrations of experiments and not applied to experiments performed by students. The benefit of this style is that students are often performing the same experiments at the same time, and they need to formulate their own conclusions concerning what the experiments mean scientifically (Domin, 1999). This ideal is not always realized due to the nature of the laboratory classroom environment. Once one student has found the answer, the answer is typically shared, and the inquiry aspect of the laboratory is lost.

This may also occur if the discovery laboratory is completed after lecture instruction, a common problem in courses where the laboratory and lecture are separate courses. Students may also make conclusions that are incorrect, leading students to develop misconceptions concerning the concept.

The final type of laboratory instruction is problem-based, in which students "create their own procedures to solve a problem and submit a written report describing the procedure, the results obtained, and the conclusions reached" (Domin, 1999, p. 545). This differs from the inquiry approach because students have a specific problem to address, versus open inquiry without a specific goal in mind. Students may be provided with a problem or may formulate their own problem. This method encourages critical thinking, but it can be difficult to manage and teach in this format. Students perform different experiments at the same time, and students must have appropriate background knowledge to address the problem.

There is no clear consensus on the best style for teaching all chemistry laboratories, based on the current literature. Beasley (1991) notes how important it is "to focus student outcomes of a laboratory experience" (p. 590). The outcomes or objectives of a laboratory are important considerations in determining the style of laboratory instruction, though there are no clear, experimentally determined guidelines or models as to how the style should be chosen.

Instructional Systems Design Models

"An instructional system may be defined as an arrangement of resources and procedures used to facilitate learning," (Gagné, Wager, Golas, & Keller, 2005, p. 18) and "instructional systems design (ISD) is the process for creating instructional systems" (p. 18). This focus on the process of designing the system, versus designing the instruction or products that support instruction is an important distinction. Though instructional design models, such as the 5E model, have been used in chemistry to design laboratory instruction, more inclusive instructional systems design research is sparse and difficult to interpret (Ansberry, & Morgan, 2005). An instructional systems design model for instructional chemistry laboratories would bring the many considerations of chemistry laboratory design into one comprehensive process.

Richey and Klein (2009) make the distinction between instructional design models that focus on the broad procedures of design and models that focus on "selection and sequencing of specific learning activities" (p. 23). For the purposes of this study, the broad instructional design models are referred to as "instructional systems design models" (Richey & Klein, 2009, p. 6), due to their systematic characteristics, while the more focused models are referred to as instructional design models. An instructional systems design model for chemistry laboratory design may include the selection of instructional design models as a part of the process, along with the selection and analysis of other elements of chemistry laboratory systems. Elements within a system are selected from possible parameters of variables of instructional design. These variables relate various strategies, concerns, or choices that may need to be considered within the design process, and an instructional systems design model provides a framework for the relationship between these variables within the design process (Reigeluth, Bunderson, & Merrill, 1978).

For example, one basic instructional systems design model is the ADDIE model, named after the five phases of the model: analysis, design, development, implementation, and evaluation (Gagné et al., 2005). These phases are process focused, describing the types of questions and concerns for the phases of design. Gagné et al. (2005) note that the steps involved in each phase of the model may differ, depending on how and where it is applied. Molenda (2003) provides support for the lack of a specific origin for the ADDIE model, and the author suggests that the ADDIE model is a starting point for the design of more complex models within the field of instructional design. An instructional systems design model for chemistry laboratory design may incorporate different questions and concerns, or variables of design, unique to this context.

Instructional Design Models for Laboratories

The Biological Sciences Curriculum Study (BSCS) organization developed the 5E model of instructional design and used it in science laboratory experiment design. The 5E model involves the five phases of "Engage, Explore, Explain, Elaborate, and Evaluate" (Ansberry, & Morgan, 2005, p. 27) in a learning cycle. This cycle allows students to experience the phases of the model in different orders or in different phases concurrently as they progress through their experience (Ansberry, & Morgan, 2005). The first step of the cycle, engage, is used to introduce students to the concepts and build their interest in the concepts, the explore step provides "hands-on experiences" (Ansberry, & Morgan, 2005, p. 28), the explain step allows the students and teacher to interact to clarify concepts, the elaborate step helps "students correct their remaining misconceptions and generalize the concepts in a broader context" (p. 28) by completing additional activities, and the teacher evaluates student understanding throughout the cycle through the evaluate step. For example, a student may start with a linear process of engaging, exploring, then explaining, but decide to return to explore further based on the explanations built. The teacher would be evaluating throughout the process. This model is based in constructivism, and it is intended to increase inquiry in lab activities (Ansberry, & Morgan, 2005).

The 5E model shares some similarities with Gagné's events of instruction, since both models organize activities to support learning (Gagné et al., 2005). Both of these models provide a sequence of events, though the events may occur in a different order. They also focus on just one part of the design requirements for a lesson, the events and activities designed to promote learning (Gagné et al., 2005).

Chemistry Laboratory Design

Research on chemistry laboratory design. Schlenker, Blanke, and Mecca, (2007) used the 5E model, or learning cycle, in designing a chemistry experiment involving carbon dioxide for the middle school level. This was a case study, demonstrating that the method could be used. Schlenker et al. (2007) note that students were often involved in more than one phase of the 5E model at the same time, but no evidence was provided to support this conclusion. Experimental comparisons between the 5E model and other forms of instruction often involve extremely different treatment conditions, making it difficult to determine if the benefit is due to the 5E model specifically or the implementation of new methods of instruction. For example, Ceylan and Geban (2009) used the 5E model to design lessons on states of matter and solubility that included laboratory experiments, which they then compared to a traditional model of teaching these topics involving lecture, discussion, and worksheets, but no laboratory experiments. Though the 5E model showed improved learning of concepts, it was a vastly different approach to the topic. The teacher held the role of the source of knowledge for the traditional method, versus the role of facilitator in the 5E model.

Bybee (2006) examined the implementation and efficacy of the 5E model in 9th through 11th grade science. When the 5E model was used to design the instructional materials for the science classes, students improved in their conceptual understanding, based on a comparison of pretest and posttest scores, regardless of prior achievement levels. The fidelity of teacher implementation of the 5E model was also observed by evaluators, and teachers were classified as low, medium, or high implementers. Students performed better on achievement tests if their teacher was a medium or high implementer, supporting the benefit of implementation of the 5E model. This also suggests that preparing teachers for implementation is an important consideration in the 5E model.

Özdilek and Özkan (2009) employed an instructional design model with a systematic approach to develop a lesson on the classification of matter for seventh grade students, and they compared the lesson to a traditional, existing lesson used at the school. A needs analysis of the traditional lesson was performed to identify issues in the existing lesson (Özdilek & Özkan, 2008). The lesson developed using instructional systems design resulted in higher levels of achievement than did the traditional lesson, though Özdilek and Özkan (2009) acknowledge that so many parts of the lessons were different that it was impossible to determine which parts were providing a benefit. Their study also does not separate the benefit of using instructional systems design from the wide range of teaching methods that were used. Özdilek and Özkan (2009) specify four key elements of instructional design used in their design. These elements were identified by Lihua and Smaldino (2003) as: "learner considerations, content organization, instructional strategies, and evaluation" (p. 155).

Other chemistry laboratory design considerations. One consideration that has been important in the design of laboratories is the physical design of the chemistry laboratory facilities. Researchers have examined design issues such as making laboratories more "environmentally friendly" (Beckrich, A., 2010, p. 12; Case Studies, 2010) and the modifications of laboratory environments required by cost (Moretti, 1997). Chemistry laboratory facilities can vary significantly, and these facilities may only allow students to perform certain laboratory experiments. For example, Moretti (1997) notes that a specialized water purification system had to be eliminated from the design of the laboratory facilities due to costs. Any experiment that relied on this water system would also have needed to be cut or modified. Design of lab facilities can also affect the way air flows through a room or the way water flows from the taps, and these design choices may require modifications to equipment or experiments (Corkern, 1991; Smucker, & Weaver, 1959).

Content organization at the undergraduate level is addressed on a broad scale by the American Chemical Society's (ACS) guidelines (2008) and evaluation procedures. Students are required to complete certain content in certified programs, but the specific organization of that content may be presented in traditional or non-traditional divisions of courses. The ACS also provides some basic guidelines for laboratory instruction. Beyond the ACS guidelines, there is little consensus about aspects of the chemistry curriculum at the undergraduate level. Approaches may range from drastically different changes to the traditional chemistry sequence, such as Reingold's (2001) implementation of Bioorganic Chemistry as an alternative to the more traditional General Chemistry, to more subtle changes across the curriculum, such as Cacciatore and Sevian's (2009) integration of green chemistry and Szalay, Zook-Gerdau, and Schurter's (2011) incorporation of forensic chemistry.

Yang and Atkinson (1998) propose a series of checklists for instructors to consider as they design laboratory experiments for undergraduate students. Though they acknowledge that the checklists are not comprehensive, these authors do provide guidelines based on their experiences as chemistry laboratory instructors. These guidelines can be used by new instructors so they can include essential details in their laboratory designs.

Additional guidelines derived from a wide selection of expert faculty members could expand and build this knowledge into a design model. Yang and Atkinson (1998) may have missed elements of laboratory design that are important for different types of institutions or laboratory styles. Incorporating more experts and findings from the literature may result in a model incorporating more of the considerations of laboratory design and more guidance in the process of design.

Model Development

Richey and Klein (2009) suggest the Delphi Method as one possible approach to model development, and they emphasize the creation of models "based upon data collected directly from designers/developers" (p. 66). The Delphi Method can be used to collect information from expert designers to determine the current practice of chemistry laboratory design. This information can then be categorized, prioritized, and organized to create a model of current design practice. Richey and Klein (2009) also note a lack of research on the development of design and development models, though there are examples of model validation research that have been completed since the Richey and Klein publication (Wilson, 2011).

Delphi Method

"The Delphi method is an iterative process to collect and distill the anonymous judgments of experts using a series of data collection and analysis techniques interspersed with feedback" (Skulmoski, Hartman, & Krahn, 2007, p. 2). This method has been used to gather information from experts in an information systems context, including addressing issues of design. This method is appropriate to studying chemistry teaching laboratory instructional systems design models, since this research is useful for using disparate information from experts to build a more inclusive model. The Delphi method has a few main design characteristics: methodological, initial question, expertise criteria, number of participants, number of rounds, mode of interaction, rigor, results analysis, verification methods, and publication (Skulmoski et al., 2007).

The Delphi method can be employed in studies that are quantitative, qualitative, or mixed methods research, depending on the research questions (Skulmoski et al., 2007). These research questions also influence the choice of initial questions in the Delphi method. The initial questions for the Delphi survey can be focused or broad, balancing the needs of the research purposes with the time that may be required to analyze answers to broad questions. The Delphi survey questions are posed to participants who are experts in the area under investigation. Adler and Ziglio (as cited in Skulmoski et al., 2007) acknowledge "four 'expertise' requirements: i) knowledge and experience with the issues under investigation; ii) capacity and willingness to participate; iii) sufficient time to participate in the Delphi; and, iv) effective communication skills" (p. 10). Once experts are identified, an appropriate number of participants must be determined. The number of participants is influenced by the homogeneity of the participant population, decision quality versus manageability, and verification. If the participant population "is homogenous, then a smaller sample of between ten to fifteen people may yield sufficient results" (Skulmoski et al., 2007, p. 10). Skulmoski et al., (2007) note the challenges of balancing decision quality and Delphi manageability. Larger group sizes may decrease the amount of error in decisions made, but they also may make it difficult to analyze the data. This issue also affects verification of the results. Larger groups suggest verified results, while smaller groups may require additional, external verification. These factors are all limited by the number of experts who actually exist in the field.

The number of rounds in the Delphi varies; though most Delphi studies employ two or three rounds (Skulmoski et al., 2007). Though more rounds may help in creating a consensus, each additional round reduces the response rate and may not be necessary to answer the research questions. These rounds can be conducted through a variety of modalities, from more traditional, paper-based approaches to internet-based approaches, such as electronic mail or surveys. The choice of modality should be appropriate to the expert participant group (Skulmoski et al., 2007).

The Delphi design characteristics influence the rigor of the research, but this is also influenced by thorough record keeping. The methods for keeping these records can influence the final rigor of the study, and electronic data gathering can facilitate accurate record keeping (Skulmoski et al., 2007). Electronic data gathering methods limit the errors introduced by transcription, and electronic methods also allow more data to be analyzed in a shorter period of time, allowing for larger reasonable samples.

The methods for analyzing data and presenting results are also important for maintaining rigor. These results may require additional verification, depending on the initial population of experts, homogeneity, and applicability to other contexts. Skulmoski et al. (2007) also emphasize the importance of including the Delphi instrument in publication of a Delphi study.

The Delphi method aligns with Reigeluth, Bunderson, and Merrill's (1978) description of construction of theory in instructional design as combining basic and applied research through determining variables, categorizing these variables, finding relationships between the variables, validating the relationships, and testing the relationships through models. The term variable is used to indicate considerations with various possible parameters that experts may decide among in designing instruction. The number of potential design variables is impractically large, requiring initial identification of the most relevant variables for a particular type of design (Merrill, & Wood, 1974). The Delphi method can be modified to align with Reigeluth et al.'s (1978) description to involve experts identifying the variables in the initial round of the Delphi method, categorizing the variables and determining relationships in the second and third rounds, and testing the model relationship through interviews concerning the model developed from the Delphi method.

Though the Delphi method is not a common method in chemistry education research, it has been used to determine if there was a consensus within the field regarding the undergraduate chemistry curriculum, particularly regarding upper division chemistry courses (Melton, Parr, Caldwell, & Sherry, 1977). This study involved very broad goals, with a heterogeneous population of experts from across the United States, requiring a large sample size. In spite of this, there was a high level of agreement between the different populations in this study, suggesting that there is a consensus within the field.

Köksal (2009) describes using the Delphi method with six experts in biology at the university level to validate an instructional design model. These experts had 3 to 14 years of teaching experience, and they possessed either a MEd or PhD degree. Köksal (2009) was able to validate the model with this small group, suggesting that a small group may be adequate for model studies in the sciences at the college level. Chemistry faculty at the community college or university level are a relatively homogeneous group, with fewer female or underrepresented minority faculty members regardless of institution type (Neuschatz, Ryan, Wesemann, & Boese, 2003; Harris, & Woods, 2009). This suggests that a small group may also be adequate in chemistry.

Study Purpose and Questions

The purpose of this study was to construct an instructional systems design model for chemistry teaching laboratories at the undergraduate level. This was accomplished through examining previous research in chemistry teaching laboratory design as well as on general instructional systems design models along with collecting data concerning practical design experiences from chemistry teaching laboratory design experts. The following research questions were addressed:

1. What variables do chemistry teaching laboratory design experts consider in planning a new chemistry teaching laboratory experiment?
    a. How is the content for the laboratory experiment determined and sequenced?
    b. How does the physical surrounding influence the experiment design?
    c. What analysis is conducted regarding students who will complete the laboratory?
    d. How do experts determine what type of laboratory style to design?
    e. How do experts design and develop the teaching materials for a new experiment?
2. How do chemistry teaching laboratory design experts prioritize and sequence the variables of instructional design when planning a new chemistry teaching laboratory experiment?
3. How do the variables of chemistry teaching laboratory design contribute to the instructional systems design model for teaching laboratory experiments?

Chapter 2

METHOD

This study used the Delphi Method for model construction, followed by verification of the model through interviews. The Delphi part of the study was conducted through electronic communications to gather information on the variables that chemistry laboratory design experts find most relevant to chemistry laboratory design, the categorization of these variables, and the determination of how these variables fit into a systematic model of instructional design. Literature review, indicated as Stage 0 in *Figure 1*, was initially conducted to build this proposal, specifically the first round of the Delphi Method. Literature reviews of research on laboratories and instructional design models was conducted between the rounds of the Delphi surveys to aid in identification and categorization of the variables and in building the model. Interviews with additional experts were used to validate the model. The stages of the proposed study are shown in *Figure 1*.

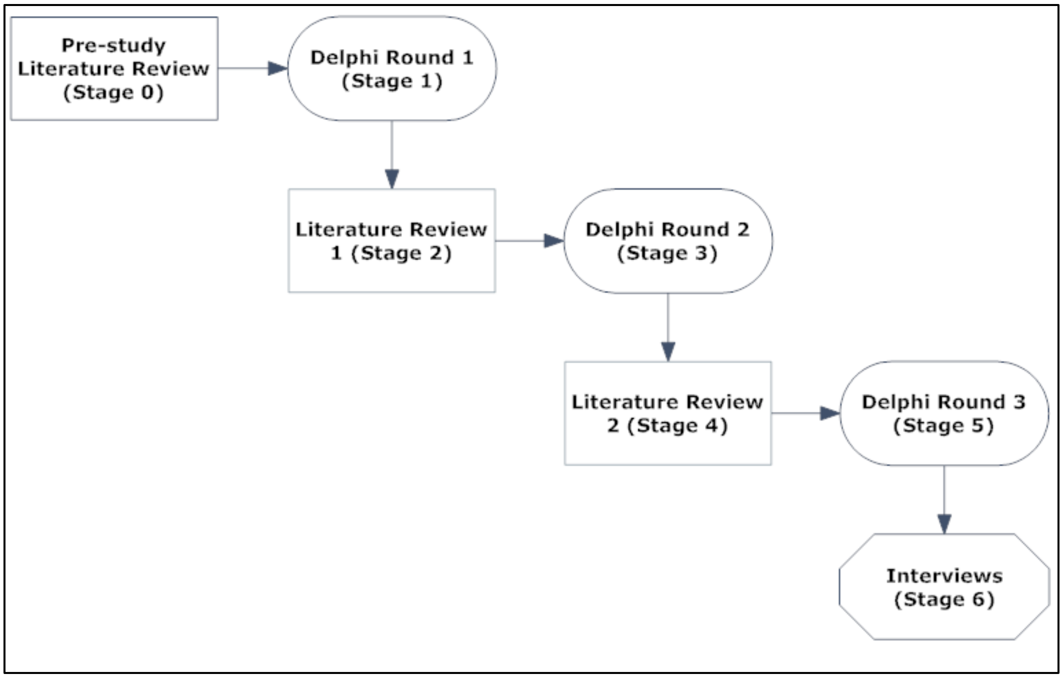

Figure 1: Stages of the proposed study. This figure depicts each stage of the study and the sequence of the stages.

Participants

Participants in the study were 16 experts in undergraduate, chemistry laboratory design. Chemistry laboratory design experts were initially identified through their publication of laboratory experiments for undergraduate chemistry in the Journal of Chemical Education. Individuals were ordered, based on the number of laboratory experiments they have authored in the Journal of Chemical Education in the past five years. Individuals with the most published laboratories were invited to participate in the Delphi or interview stages of the study, and to nominate additional individuals who may be appropriate to the study, based on their publication of laboratory experiments in alternate locations, such as laboratory manuals, other journals, or institution-specific materials. Thirteen of the experts were assigned to the Delphi stages (stages one, three, and five) of the study. Three of the experts were identified to review the revised model by providing feedback through an informal interview process.

Data Sources

Data for this study was gathered through Delphi surveys based on variables from the literature and interviews. Skulmoski et al. (2007) note that Delphi studies are often validated with interviews or other follow up methods in dissertation research. Data sources included chemistry laboratory experts and the literature.

Literature review. The literature on design and laboratories was initially used, and continued to be examined more deeply, to identify common categories of variables and their possible relationships that may be significant to chemistry laboratory experiment design. The categories of variables identified in the literature have been used in designing the questions for the first round of the Delphi. The relationship of the literature review (stage 0) to the first round Delphi questions is further explained in the methods for the first round of the Delphi study. The first round of the Delphi (stage 1) was used to gather data concerning the specific variables that correspond to the categories from the literature.

Next, the variables identified in the first round of the Delphi were used along with another review of the literature to create the questions for the second round of the Delphi. The literature review (stage 2) was used to determine variables that are synonymous and to clarify the terminology for the second round of the Delphi (stage 3). In the second round of the Delphi, the variables were categorized by importance and phase of the design process.

The categories identified in round two of the Delphi and further literature review (stage 4) of how these categories relate to models in the literature was used to construct the model, which was verified in round three of the Delphi (stage 5). This model was compared to existing instructional systems design models before the final, follow up interviews (stage 6).

Chemistry laboratory expert data. Data from the chemistry laboratory experts was gathered mainly through electronic communications. These included electronic mail and surveys. The expert interviews were conducted via telephone, teleconferencing software, or face to face, depending on expert preference and location.

Materials for this study included electronic survey instruments for each round of the Delphi Method. The initial Delphi questions were broad, to allow the collection of a wide variety of possible variables from the expert population. These questions were presented along with relevant demographic questions, to verify that the participants are chemistry laboratory design experts. The second and third round questions were narrower, as the instructional system design model was developed.

Demographic information was gathered about the chemistry laboratory experts who participated in the Delphi study. Demographic information collected included degree completed, major, the type of institution where the individual teaches, the level of chemistry courses taught, years of experience teaching chemistry laboratories, approximate number of laboratory experiments designed, training completed about designing chemistry laboratory experiments for teaching laboratories, and beliefs concerning how students learn at different levels of chemistry. These data were also collected from individuals who participated in the follow up interviews.

First round of the Delphi study. Some major categories of variables were identified in the Stage 0 literature review of this study. These are categories of variables that were identified as possible considerations in the design of chemistry laboratories. These are content variables, assessment, physical considerations, student considerations, laboratory type or style choice, teaching materials issues, experiment considerations, and teacher considerations. The Delphi study first round questions about these categories were preceded with definitions of terms. These definitions included:

- Laboratory experiment – This refers to an experiment performed in a laboratory classroom by undergraduate students.
- Laboratory facilities – This refers to the equipment, lab room, support areas, hallways, or any other facility details that may influence the laboratory environment.
- Chemical experiment – This refers to the actual experimental methods or procedures used in a laboratory experiment.

Content variables. The organization of content in the chemistry laboratories is a source of concern throughout the literature. Even though there is general consensus on some common items that should be addressed throughout chemistry degree programs, these items may be arranged in various ways within individual chemistry courses and laboratory experiments both within the chemistry program and within courses serving the chemistry non-majors population (American Chemical Society, 2008; Cacciatore, & Sevian, 2009; Reingold, 2001). Organization of the content may relate to how the topics are sequenced within the chemistry teaching laboratory, what topics are addressed, and the depth the topics are addressed. The specific content variables were identified by asking the chemistry design experts to list content variables they consider when creating a new laboratory. The questions to elicit this information were:

1. How do you decide what chemistry content a new laboratory experiment will include?
2. How do you decide what outcomes or competencies students need to be able to complete by the end of a laboratory? Essentially, how do you decide what students need to be able to do?
3. What, if any, professional or accreditation guidelines do you consider when deciding on the content of a new laboratory experiment?
4. How do you determine where a particular laboratory will fit into the sequence of a course?

Assessment. The chemistry laboratory is assessed in a variety of different ways, and choosing appropriate assessments can be a challenge. The types of assessments chosen vary based on outcomes of programs and courses, logistics of conducting various types of assessments, and other considerations (Towns, 2010). The questions to elicit information about this category were:

1. How do you assess students in the laboratory (reports, worksheets, written exams, practical exams, etc.)?
2. How do you choose the type of assessment(s)?
3. How do you assess the success of a specific laboratory experiment?

Physical - Facilities, logistical, and cost considerations. Physical considerations, including facilities, logistical and cost, can limit or change the types of experiments that are performed, and they may influence how the experiments are performed (Beckrich, 2010, p. 12; Case Studies, 2010; Moretti, 1997; Corkern, 1991; Smucker, & Weaver, 1959). These physical considerations may include the design characteristics of existing laboratory facilities, the safety of the chemistry experiments for the environment and individuals, time and space limitations, or cost limitations related to materials, equipment, or facilities. The questions to elicit information about the physical considerations were:

1. How do the existing laboratory facilities influence your laboratory experiment designs?
2. What aspects of safety for individuals in the laboratory and safety for the environment do you consider when designing laboratory experiments?

3. What time and space limitations do you consider when designing laboratory experiments and how do those influence your laboratory experiment designs?
4. How do non-personnel costs (anything but faculty and staff) influence your laboratory experiment designs?

Student considerations. Characteristics of the student population that will be completing a particular laboratory experiment are considerations when designing chemistry laboratory experiments (American Chemical Society, 2008; Reingold, 2001; Szalay et al., 2011). These considerations are often related to the organization of content, but they may also be related to safety and materials design. The student considerations were addressed with the following questions:

1. What information about students do you gather when designing a laboratory experiment?
2. How do you gather this information?
3. How does information about the students influence your laboratory experiment designs?

Choice of laboratory style or type. Laboratory style, more commonly called type, is another major consideration when designing chemistry laboratory experiments, and there have been a variety of studies to determine how these considerations may influence student learning (Domin, 1999; Brown et al., 2006; Cacciatore, & Sevian, 2009; Lagowski, 1998). The research in the field is somewhat inconclusive, so expert chemistry designers may use a variety of methods to choose an appropriate laboratory style. Questions to determine these methods included:

1. What types of laboratory experiments do you design? Examples of laboratory experiment types include: expository, open inquiry, guided inquiry, and problem- based. Please, include a brief explanation of the type.
2. How do you decide what type of laboratory experiment to design?

Teaching material issues. Expert chemistry laboratory designers may choose from a variety of materials and material designs when creating experiments, though the reasons for these choices often lack clear, research-based support (Cacciatore, & Sevian, 2009; Cacciatore, 2010, Özdilek, & Özkan, 2009). Due to the diverse options for material design, chemistry design experts may be using a variety of strategies to determine the best method for writing instructional materials. Questions to investigate these methods included:

1. What types of written materials or media, if any, do you create for student use when you design laboratory experiments?
2. What types of written materials or media, if any, do you create for teacher or faculty use when you design laboratory experiments?
3. What types of written materials or media, if any, do you create for staff use when you design laboratory experiments?
4. How do you decide what types of information to include in written laboratory materials?
5. How do you format or organize this information?

Experiment considerations. There is a wide array of information available for chemistry laboratory design experts covering the design and optimization of specific experimental conditions for chemistry laboratory experiments (Dean, Miller, & Brückner, 2011; Noey, Curtis, Tam, Pham, & Jones, 2011; Lang, Miller, & Nowak, 2006). Chemistry laboratory experiment designers can often find detailed information in the literature about how to modify and optimize chemical experiments for the teaching laboratory. Experts may also investigate new chemical experiments, since many of the individuals who design chemistry laboratory experiments are also chemistry practitioners, experienced in designing chemistry experiments beyond the classroom. Questions considering the design and optimization of chemical experiments for chemistry teaching laboratories included:

1. How do you choose and test chemical experiments or procedures that you plan to incorporate into your laboratory experiment designs?
2. What issues do you consider when planning the chemical experiment or procedure?

Faculty considerations. Faculty or instructor preparation may influence the laboratory design characteristics that are reasonable, manageable, or successful (Mohrig et al., 2007; Roehrig, & Luft, 2004). The individuals teaching chemistry laboratories can vary from graduate teaching assistants with little prior teaching experience to individuals with extensive teaching experience. Faculty members teaching the laboratories may also have varying levels of experience with teaching methods, chemistry content knowledge, chemistry experimental methods, and chemistry equipment. Questions related to faculty considerations included:

1. When you design a chemistry laboratory experiment, who will typically be directly supervising the students in the laboratory room?
2. How do you modify laboratory experiments based on who will teach them?

Other considerations. The literature may not address every consideration that chemistry laboratory design experts address when designing new laboratory experiments. Questions related to these other considerations included:

1. Are there any issues that you consider when designing a laboratory experiment that have not been addressed? If yes, please describe them.

Second round of the Delphi study. Variables from the first round of the Delphi were identified. These variables were used to create a new survey. The chemistry design experts were asked to prioritize and order these variables. This round helped determine the importance and relationships between the variables and it verified the importance of specific variables. The experts were asked to rank the importance of the variables from the first round of the Delphi study into categories from very important, with a value of five, to very unimportant, with a value of one. They were also asked to order the variables by when they are important to the design process, varying from the beginning of the process to the end. Both the importance and order questions included the option of "not applicable". Finally, they were asked to describe any additional variables they have considered after seeing the second round of Delphi questions.

Third round of the Delphi study. The organization of variables from the second round of the Delphi was used to create a preliminary model of instructional systems design for chemistry laboratory experiments. The third round of the Delphi helped to verify this preliminary model and determine any major gaps or concerns. Experts were provided with the preliminary model and asked to identify issues with the model. The format of the questions in this round included both open response and rating scales. Answers to these questions were used to create the final instructional systems design model.

Verification interviews. Interview participants were asked to review the model of instructional systems design for chemistry laboratory experiments produced from the Delphi study. They were provided with the model approximately one week before the interview to allow time to review the model. During the interview, they were asked to provide feedback that was used to verify or further refine the model. Feedback was elicited by asking open-ended questions, such as:

1. Would you be able to design a chemistry teaching laboratory from this model?
2. What improvements would you suggest to this model?
3. Would you consider using this model to design chemistry teaching laboratories?

Procedures

Chemistry laboratory design experts were initially identified through their publication of laboratory experiments for undergraduate chemistry in the Journal of Chemical Education. Individuals were ordered, based on the number of laboratory experiments they have authored in the Journal of Chemical Education in the past five years. Individuals with the most published laboratory experiments were invited to participate in the Delphi or interview stage of the study, and to nominate additional individuals who may be appropriate to the study, based on their publication of laboratory experiments in alternate locations, such as laboratory manuals, other journals, or institution-specific materials. Sixteen experts were identified through this method, thirteen for the Delphi portion of the study and three for the verification interviews. Of the thirteen experts in the Delphi portion of the study, at least ten participated in each round of the surveys, though this may be different individuals for each round. The stages of the proposed study are listed in *Figure 2*. The stage number indicates the order in which the stages were conducted. This includes stage 0, which indicates that the initial literature review was conducted to design the study.

Figure 2 *Stages of the proposed study.*		
Stage Number	Stage Name	Purpose
0	Pre-study literature review	Determine existing categories of variables from the literature and use these categories to write the questions for the first round of the Delphi (completed and included in this proposal).
1	First Round of the Delphi	Collect data from experts on the variables they use when designing chemistry laboratories.
2	Literature Review 1	Determine synonyms of variable names identified in the first round of the data. Use these synonyms and the first round Delphi data to write the questions for the second round of the Delphi.
3	Second Round of the Delphi	Collect data on how experts would order and prioritize the variables.
4	Literature Review 2	Compare the order and priority of variables to existing models. Use this comparison to aid in building a model for chemistry laboratory experiment design.
5	Third Round of the Delphi	Collect the experts' feedback on the model's usefulness, accuracy, and clarity to create a revised model.
6	Interviews	Collect experts' feedback on the revised model to validate or further refine the model.

Figure 2: Stages of the proposed study. This figure provides a description of the type of stage and the purpose for each stage in the study.

In stage one, the experts were provided with a link to an electronic survey containing the first round of Delphi questions. They had two weeks to complete and submit the survey. Data were compiled and analyzed to determine the variables identified by the chemistry laboratory design experts in each category. Since the experts may use alternate terms for the same variable, the stage two literature review was used to determine terms that indicate the same variable. The data may also suggest an order or priority to the variables, or they may suggest a new category or categories that can be combined.

These experts were provided with a link to an electronic survey containing the second round of Delphi questions. They had one week to complete and submit the survey. Since this survey involved ranking the importance and sequencing the variables, it was expected take less time to complete than the first round of Delphi questions. The ranking and sequencing data were analyzed to determine the perceived importance of the variables and their relationships. This information was used along with a review of the literature to construct a preliminary model of instructional systems design for chemistry laboratory experiments.

Finally, the experts were provided with a link to an electronic survey containing the preliminary design model and the third round of Delphi questions. They had one week to complete and submit the survey. These data were used to construct a revised model of instructional systems design for chemistry laboratory experiments.

Finally, three chemistry laboratory design experts who did not participate in the Delphi surveys (stages one, three, and five) were asked to review and provide feedback on the revised model. They were provided with the model a week before the interview, then interviewed face-to-face, by telephone, or with internet video conferencing. This allowed the experts to designate areas of the model that were confusing or impractical, while ensuring that their feedback was properly interpreted. Limiting the interviews to face-to-face or telephone with internet conferencing allowed the experts to indicate the parts of the model being discussed, by pointing to them or verbally identifying their location. This information was used to clarify and verify the model as needed. Interviews were intended to reveal issues with the terminology, diagrams, or other details of the model that may need to be modified before the model can be effectively implemented.

Data Analysis

Data analysis for this study focused on building a consensus based on the chemistry laboratory design experts' responses to each round of the Delphi. The responses from the first round of the Delphi were analyzed to determine which responses may indicate the same variables, such as using slightly different terminology to indicate the same variable. Literature review (stage 2) was used to determine if the experts called the same variable by different names. Domin (1999) described more than one term that applies to many of the styles or types of chemistry laboratories, and this possibility of multiple terms was considered in analyzing the variables. Terms with the same meaning were combined for building the second round of the Delphi. The demographic information collected in the first round of the Delphi was used to describe the expert population.

The data from the second round of the Delphi were analyzed through descriptive statistics. Mean scores and frequencies were used to rank the variables by importance and to order them within the design process. Additional suggested variables were analyzed to determine if they fit with an existing variable or if they indicate a variable that was not identified in the first round of the study. Literature review (stage 4) was used to determine if the rank and order of the variables identified by the chemistry laboratory design experts matches existing models of instructional systems design, such as the ADDIE model, or if there are similarities to models of instructional design, such as the 5E model. The data from the experts were used in combination with the literature review to build a model of chemistry laboratory design.

Data from the third round of the Delphi were used to determine if the chemistry laboratory design model represents a consensus of expert design practices. The number and type of questions were based on the characteristics of the model, and may require a variety of analysis methods. The data were used to refine or modify the model as needed.

Data from the interviews were analyzed to determine if the experts in the interviews agree with the experts who participated in the Delphi stages of the study. Interviewee feedback was matched to the data gathered throughout the study to determine if there are any gaps in the model, what the gaps are, and how they might be addressed. Interviewee responses were compared to determine if the experts agreed on areas that needed to be addressed in the final model.

Chapter 3

RESULTS

Data were collected through six stages, including three rounds of a Delphi survey, two rounds of literature review, and one stage of follow up interviews. Results are reported below for each of the stages of this study.

Delphi Round One – Verification of Expert Status and Identification of Variables in Design of Undergraduate Chemistry Laboratories (Stage One)

The first round of the Delphi survey portion of the study was designed to provide a broad perspective on how chemistry experts approach the design of new chemistry teaching laboratories. This round was also designed to gather some basic demographic information concerning the experts to ensure that the experts had the appropriate expertise for the study, to evaluate their beliefs concerning how students learn most effectively, and to verify the homogeneity of the participant population to support the small sample size. Though the literature suggests that chemistry experts are a relatively homogeneous group, demographic questions were asked to verify this consistency within the participant group (Neuschatz, et al., 2003; Harris, & Woods, 2009). The beliefs of how students learn most effectively may relate to choices experts make in the design process, and significant differences in the responses from the participants may indicate a lack of homogeneity in their approach to instruction. Questions for this round included open-response and multiple choice questions in an online survey (Appendix A1).

Demographic and belief data gathered from chemistry experts. Demographic data including degree level, major, type of institution where the individual teaches, levels of courses taught, years of experience, number of chemistry laboratories designed, previous training, and beliefs concerning how students learn best were gathered through the first round of the Delphi survey (Appendix A1). These questions were also asked during the interviews, and these data are combined in Table 1 and Table 2. These data support identification of these individuals as experts in chemistry laboratory design at the undergraduate level. Most of the participants have doctoral degrees in chemistry. They all have six or more years of experience teaching chemistry laboratories, and most of them have developed seven or more experiments. None of them received any formal training in chemistry laboratory design.

Table 2 indicates the beliefs of the experts concerning how students at different levels of chemistry learn best. There is a clear pattern of beliefs from direct instruction and specific directions to more student-directed laboratories as the students advance through a program. This pattern is also reflected in the open-response questions within the survey.

Table 1
Delphi round 1 Demographic Data.

Question Number	Demographic Questions	Responses	Count
1	Please select your highest degree completed:	Bachelor's degree Master's degree Doctoral degree Other (please specify):	0 4 11 1 (doctoral equivalent)
2	Major of highest degree	Chemistry, any specialization Other science or engineering discipline Non-science or engineering discipline	13 1 1
3	Type of institution where you teach or design laboratories or have most recently taught or designed laboratories:	2-year college 4-year college, no chemistry graduate program 4-year college, with a chemistry graduate program	1 5 9
4	Level of undergraduate chemistry courses of any type you have taught (select all that apply):	First year Second year Third year Fourth year	12 11 9 5
5	Years of teaching undergraduate chemistry laboratories:	0-2 years completed 3-5 years completed 6-10 years completed More than 10 years	0 1 6 8
6	Number of undergraduate chemistry laboratory experiments you have designed that have been used in the laboratory classroom:	0-3 experiments 4-7 experiments 7-10 experiments More than 10 experiments	2 2 3 8
7	What training, if any did you complete on how to design or modify new chemistry laboratory experiments?	Open-response	Responses all indicated that no laboratory-specific training had been completed.

Note: These data include demographic information from both survey and interview participants.

Table 2

Delphi round 1 Responses to Question 8: "What part of this spectrum would best fit the way you believe students learn best at each level of chemistry laboratory?" Years indicate the year the chemistry course would fit within the curriculum.

Response Options:	Everything students learn needs to be told to them directly by the instructor or book such as with laboratories with detailed steps.	Most of what students learn needs to be told to them directly.	There should be an even balance of students being told directions and completing their own planning.	Most of what students learn should be planned by the students.	Students need to discover everything they learn, such as with laboratories planned and conducted entirely by the students.
First Year	4	6	5	0	0
Second Year	0	5	10	0	0
Third Year	0	0	8	7	0
Fourth Year	0	0	1	10	4

Note: These data include demographic information from both survey and interview participants.

Round 1 Delphi survey open-response answers to identify variables in the design of undergraduate chemistry laboratories. Experts provided answers to open-response survey questions during the first round of the Delphi survey

(Appendix A1). These answers are organized and categorized to determine the variables for the second round of the Delphi survey. The variables derived from each question in the first round of the Delphi survey are listed in Table 3. The term variable indicates considerations with various possible parameters that experts may decide among in designing instruction (Merrill, & Wood, 1974).

The variables shown in Table 3 were based on the responses to open-response questions in the first round of the Delphi survey. Each participant could provide multiple responses to the questions or skip the question. Though these responses were often worded differently, there were common themes that appeared throughout. The intent of this categorization was to identify as many of the variables present in the answers as possible.

Table 3

Delphi round 1 open-response answers to questions to determine the important variables in undergraduate chemistry laboratory design.

Question Number	Question	Variables	Count
9	How do you decide what chemistry content a new laboratory experiment will include?	Based on the lecture content	6
		Emphasize laboratory skills	3
		Significance to students (interest)	2
		Ease of performance	2
		With a team of teachers	1
		Identification of goals	1
		Based on laboratories collected from literature	1
		Safety of laboratories	1
		Existing student skills	1
10	How do you decide what outcomes or competencies students need to be able to complete by the end of a laboratory? Essentially, how do you decide what students need to be able to do?	Based on the lecture content	5
		Specific laboratory skills	2
		Specific technology skills	2
		Sequencing outcomes to develop research skills	2
		Consistency with student abilities	2
		Ensuring application and utilization of concepts	2
		With a team	1
		Reasonable within time period	1
		Interesting/significant to students	1
		Examining gaps in the curriculum	1
		Examination of skills essential to industry	1
		Retrofitting laboratories to fit new requirements	1
		Addressing misconceptions	1
11	What, if any, professional or accreditation guidelines do you consider when you design a new laboratory experiment?	Safety guidelines	2
		Institutional accreditation	1
		Program level requirements	1
12	How do you determine where a particular laboratory will fit into the sequence	Sequencing based on the lecture	9
		Sequencing to allow students to progress in laboratory responsibility and autonomy	3
		Facilities and equipment limitations	1

	of a course?	Coordinating the workload	1
13	How do you assess students in the laboratory (reports, worksheets, written exams, practical exams, etc.)?	Written reports Exams Worksheets Papers Laboratory notebooks Quizzes Lab practical exams (Instructor evaluations of lab skills or preparation) Based on accuracy of results Oral one-on-one Individual presentations Poster sessions Graphs	9 7 3 2 2 2 2 1 1 1 1 1
14	How do you choose the type of assessment(s)?	Basing assessments on the type of experiments performed In collaboration with a team Similarity to the science students will perform eventually Labor required for the assessment type Challenge in consistently grading the assessment type Based on individual teaching style Modifications based on consideration of anti-cheating strategies	3 2 2 2 1 1 1
15	How do you assess the success of a specific laboratory experiment?	Good laboratory results Student achievement of outcomes and skills How the laboratory supports the lecture content Refinement over time Development of problem solving skills Completion of assignments on time Survey of students for usefulness of experiment Evaluation at the end of the lab sequence of experimental skills Use assessment to "close the loop"	5 4 2 2 2 1 1 1 1
16	How do the existing laboratory facilities influence	Need essential laboratory equipment Appropriate safety materials (hoods, etc.)	5 2

	your laboratory experiment designs?	Modification of laboratories based on equipment	2
		Group vs. individual room design	1
		Noise levels	1
		Justification of acquiring new equipment	1
17	What aspects of safety for individuals in the laboratory and safety for the environment do you consider when designing laboratory experiments?	Avoidance of toxic chemicals and wastes	8
		Green or household chemistry	5
		Use of microscale techniques	2
		Routine personal safety equipment	2
		Informing students of hazards	1
18	What time and space limitations do you consider when designing laboratory experiments and how do those influence your laboratory experiment designs?	Limiting experiments to a single session	8
		Maximum students per laboratory	4
		Shared equipment/computers	3
		Limitation variations based on course level	1
		Planning for time to discuss results	1
		Time for set up or break down	1
19	How do non-personnel costs (anything but faculty and staff) influence your laboratory experiment designs?	Chemical and materials costs	6
		Existing equipment and cost of new equipment	5
		Disposal costs	1
		Shared glassware	1
		Micro-scale and other minimization of materials	1
20	What information about students do you gather when designing a laboratory experiment?	Previous experience with students and designer intuition	5
		Academic background	3
		Area of studies	2
		Age	1
		Interests	1
		Curriculum	1
		Assume students have no prior experience	1
		Laboratory evaluations	1

		Determining information students should have before they start a particular experiment	1
21	How do you gather this information?	Previous experience with students Surveys Observations Assumptions	2 1 1 1
22	How does information about the students influence your laboratory experiment designs?	Adapting difficulty to changing student abilities Consideration of course pre-requisites Adapting to meet student interests	3 2 1
23	What types of laboratory experiments do you design? Examples of laboratory experiment types include: expository, open inquiry, guided inquiry, and problem- based. Please, include a brief explanation of the type.	Expository (proof of concept, determination of a value, cook book) Guided inquiry Problem-based More inquiry based as a student progresses Student designed experiments Open inquiry	6 5 5 3 2 2
24	How do you decide what type of laboratory experiment to design?	Based on the subject/chemistry Interest (designers or students) More inquiry based as a course progresses Based on belief of how students learn best	4 3 3 2
25	What types of written materials or media, if any, do you create for student use when you design laboratory experiments?	Laboratory handout/text/manual (print or web) Online support materials (videos, pictures, websites, spectra) Presentation materials (Power points) Data sheets	10 4 2 1
26	What types of	Instructor notes, text, or lab	8

	written materials or media, if any, do you create for teacher or faculty use when you design laboratory experiments?	supplement with issues concerning the experiment	
		Equipment and materials list	3
		Expected results	3
		Marking or grading guides	2
		List of what to order	2
		How to make solutions	1
27	What types of written materials or media, if any, do you create for staff use when you design laboratory experiments?	Information provided to instructors	8
		Preparation information for experiments	4
28	How do you decide what types of information to include in written laboratory materials?	Based on a specific material format	3
		Balancing what is needed to do the experiment with not providing too much information	3
		Based on experience with students	2
		Considering the level of content	2
		Feedback from instructors or teaching assistants	2
29	How do you format or organize this information?	Using a specific format for a course	7
		Step-by-step instructions	4
		Paper or web-based	4
		Gathering information that applies to more than one experiment in one place	2
		Coordinating online supplements to experiments	1
30	How do you choose and test chemical experiments or procedures that you plan to incorporate into your laboratory experiment designs?	Testing a new laboratory with students	5
		Testing a new laboratory myself, or with instructors or teaching assistants	4
		Fits into the right amount of time	3
		From my current research experience	2
		Based on how it fits with the curriculum/content	2
		Difficulty of the experiment	2
		Based on cost and budget	2
		From experiments in the literature	2
		Based on safety	1

		Repeatability of the experiment	1
31	What issues do you consider when planning the chemical experiment or procedure?	Safety	6
		Time limitations	4
		How well the results illustrate the concept	4
		Cost/budget	3
		Difficulty, ease of completion	3
		Resource limitations	2
		Student interest and motivation	2
		Required student skills	2
		Success of experiment	2
		Ethical considerations	1
		Ability of instructors or teaching assistants to guide students through the procedure	1
32	When you design a chemistry laboratory experiment, who will typically be directly supervising the students in the laboratory room?	Myself	7
		Other faculty members	4
		Teaching assistants who are students	4
		Staff	2
33	How do you modify laboratory experiments based on who will teach them?	Training or guides for those who will teach it	4
		Consideration of teaching assistant skills	2
34	Are there any issues that you consider when designing a laboratory experiment that have not been addressed? If yes, please describe them.	Making experiments relevant/applicable to industry, graduate school, and research	2
		Student time to prepare for an experiment	1
		Keeping processes modern	1
		Designing to avoid academic dishonesty	1
		How the course fits into the program	1

Note: 12 participants completed the open-response questions. Participants could provide multiple responses or skip the question.

Participants answered the open-response questions with specific considerations relevant to the question. They skipped few questions, and often provided detailed responses. Though the specific examples clarifying the responses varied widely, certain responses were very similar between participants and between questions. For example, for question nine, "How do you decide what chemistry content a new laboratory experiment will include?" six different participants mentioned the lecture as a source of content as either part or all of their response. These participants included examples from their experience to demonstrate how they use the lecture to guide content, but these examples demonstrated the relationship between the content of the laboratory and the content from the lecture. This specific content varied between participant responses due to the variation in the courses and content included in their examples. This indicated that "Based on the lecture content" is considered by the participants, though with different choices among the possible parameters, as is expected of a variable.

These variables are ordered by the number of times they were mentioned in each response to the questions in the survey. Some variables appear in more than one answer, such as responses indicating the lecture as a source of content. The variable categories were further combined, and literature review was used in the second stage of the study to create the questions for the second round of the Delphi survey.

Survey Open-Response Categorization of Answers from the First Round of the Delphi Survey to Create Questions for Round Two of the Delphi Survey (Stage Two)

Stage two of this study involved categorizing the variables into groups to facilitate creating questions for round two of the Delphi survey. Variables listed in Table 3 that were mentioned more than once were combined. Similar variables were combined to create variable themes, when applicable. For example, variables related to basing laboratory design on the lecture content were mentioned in questions 9, 10, 12, 15, 24, and 30 (see Table 3). These items were combined to form the variable theme "Based on the lecture" in Table 4 below. These variable themes were then used to create the questions for the second round of the Delphi survey in Table 4, such as "Basing the laboratory experiment on the material in lecture" as the stem for questions in the survey.

Most variable themes were supported by more than one response, and from more than one question. The exceptions to this support were themes 29 and 45 from Table 4, covering themes involving noise and ethics, respectively. Both of these themes are supported by the literature. There is a variety of discussions of laboratory room designs that address the issue of noise, particularly the noise from activities outside the laboratory room and the noise from fume hoods, an essential piece of safety equipment (Lewis, 1947; Butcher, Mayo, Pike, Foote, Hotham, & Page, 1985; Saunders, 1987). Ethics, particularly scientific ethics, are recognized as a vital concern in chemistry instruction, though there are often challenges with integrating it into laboratory instruction (Gillette, 1991; Kandel, 1994; Kovac, 1996). Though noise and ethics were only mentioned by one participant each in the responses to the first round of the Delphi survey, their significance in the literature indicates that these two variable themes should be considered in the second round of the Delphi survey.

Question 19 in Table 4 integrated two themes involving costs or budget considerations and limited amount or availability of laboratory equipment into one question. The responses from the first round survey indicated that these two themes were closely linked, since they were consistently mentioned together. The main cost concern from the responses was the concern of equipment or material costs, and that this cost limited the quantity of equipment that could be used for any particular experiment.

One item mentioned in the round one survey was the need to use the information gathered throughout the lab to “close the loop,” as noted in Table 3, or essentially guide revision of the laboratory experiments. This suggests that the variables may have an iterative or circular relationship, versus a linear relationship.

Table 4

Laboratory Design Variable Themes That Emerged from Round One of the Delphi and Corresponding Questions for Round Two of the Delphi

Variable Theme	Q #	Questions for Second Round
Based on lecture	1	Basing the laboratory experiment on the material in lecture
Based on laboratories from the literature	2	Basing the design on laboratory experiments in the literature
Time to conduct experiment	3	The amount of time needed to conduct the experiment
Planning time to discuss results	4	Planning class time to discuss results
Evaluation of experimental skills at the end of a laboratory sequence or program	5	Planning for including experimental skills students should have at the end of a laboratory sequence or program.
Emphasizing appropriate laboratory skills (industry, research, grad school, etc.) including technological skills	6	Emphasizing appropriate laboratory and technological skills based on skills needed for industry, research, or graduate school
Determining goals, outcomes, and skills for the laboratory	7	Determining appropriate goals, outcomes, and skills for the laboratory experiment
Student interest or motivation	8	Developing laboratories that increase student interest or motivation
Difficulty of performing the laboratory	9	Matching the difficulty of performing the experiment and student skills
Addressing misconceptions	10	Addressing student misconceptions
With a team	11	Working with a team to develop new laboratories, such as consulting other instructors
Safety	12	Determining the safety considerations, hazards, and safety equipment for an experiment
Updating laboratories to meet new requirements, methods, or needs	13	Re-purposing existing laboratories to meet new requirements, methods, or needs
Determining the appropriate level of inquiry a student should experience for a particular experiment	14	Determining the appropriate level of inquiry a student should experience for a particular experiment
Determining the appropriate level of autonomy, or responsibility a student should experience for a particular experiment	15	Determining the appropriate level of autonomy or responsibility a student should experience for a particular experiment

Determining the type of laboratory (expository, open inquiry, guided inquiry, problem- based, and student designed) appropriate to the experiment.	16	Determining the type of laboratory (expository, open inquiry, guided inquiry, problem- based, and student designed) appropriate to the experiment.
Examining the curriculum at a broad level (program, course) for gaps or needs	17	Examining the curriculum at a broad level (program, course) for gaps or needs
Institutional or program level accreditation	18	Considering institutional or program level accreditation
Costs or budget considerations, limited amount or availability of laboratory equipment	19	Costs or budget considerations, such as considering the number, availability, or price of laboratory equipment needed for an experiment
Determining how much labor would be needed to prepare and run a particular experiment	20	Determining how much labor would be needed to prepare and support a particular experiment
Choosing a type of assessment for a particular experiment	21	Choosing a type of assessment for a particular experiment
Determining the amount of labor needed to perform assessments for an experiment	22	Determining the amount of labor needed to perform assessments for an experiment
Consistency in grading, either within a course or between instructors	23	Developing materials to ensure consistency in grading, such as rubrics or keys, either within a course or between instructors
Allowing individual instructor variations in conducting laboratories	24	Developing laboratories that allow individual instructor variations in conducting laboratories
Designing to support academic honesty (anti-cheating or plagiarism)	25	Designing to support academic honesty (preventing cheating or plagiarism)
An experiment with repeatable, consistently good results	26	Developing an experiment with repeatable, interpretable results
Developing problem-solving skills	27	Developing problem-solving skills
Determining if a laboratory should be conducted individually, in pairs, or in groups	28	Determining if a laboratory should be conducted individually, in pairs, or in groups
Considering the noise level of the room	29	Considering the noise level of the room
Avoidance of toxic chemicals or wastes through the use of less	30	Avoidance of toxic chemicals or wastes through the use of less toxic

toxic alternatives such as green chemistry or household chemistry		alternatives such as green chemistry or household chemistry
Decreasing the amount of toxic chemicals or wastes through microscale techniques	31	Decreasing the amount of toxic chemicals or wastes through microscale techniques
Determining how to inform students of the safety hazards	32	Determining how to inform students of the safety hazards
Using your experience and intuition to make design choices	33	Using your experience and intuition to make design choices
Gathering data about a laboratory, such as surveys, observations, or results, to make design choices	34	Gathering data about a laboratory, such as surveys, observations, student feedback, or results, to make design choices
Testing an experiment with students, faculty (other than yourself), or teaching assistants before it is fully implemented for courses	35	Testing an experiment with students, faculty (other than yourself), or teaching assistants before it is fully implemented for courses
Including materials or media that follow a particular format throughout a course	36	Creating materials or media that follow a consistent format throughout a course
Creating a laboratory handout, text, manual, data sheet, or other written material for an experiment (paper or electronic)	37	Creating a laboratory handout, text, manual, data sheet, or other written material for an experiment (paper or electronic)
Creating presentation materials for an experiment	38	Creating presentation materials for an experiment
Creating or gathering media, such as videos, pictures, spectra, course sites (such as BlackBoard), and related materials	39	Creating or gathering media, such as videos, pictures, spectra, course sites (such as BlackBoard), and related materials
Creating lists of materials for ordering and preparing for an experiment	40	Creating lists of materials for ordering and preparing for an experiment
Creating instructions on how to prepare solutions, equipment, or other materials for an experiment	41	Creating instructions on how to prepare solutions, equipment, or other materials for an experiment
Creating an instructor guide with notes, text, or lab supplements	42	Creating an instructor guide with notes, text, or lab supplements
Creating appendixes or other collections of information on	43	Creating appendices or other collections of information on how to

how to perform common techniques or use common equipment		perform common techniques or use common equipment
Considering other individuals who may teach this laboratory experiment	44	Considering other individuals who may teach this laboratory experiment, such as other faculty, teaching assistants, staff, or others who may read the experiment if it is published
Considering the ethics of conducting the experiment	45	Considering the ethics of conducting the experiment
Creating training or guides for others who may teach this laboratory experiment	46	Creating training or guides for others who may teach this laboratory experiment
Time needed for students to prepare for an experiment	47	Considering the time needed for students to prepare for an experiment

Note: The "Q #" column indicates the question number from the second round Delphi survey.

Delphi Round Two (Stage Three)

The second round of the Delphi survey included questions (Table 4) based on the answers from the first round of the survey. The purpose of the second round of the Delphi survey was to determine the importance and order of the variable themes derived from the first round, and to determine if any items were missed from the first round. This was accomplished through the use of rating scales for most of the questions, with one open response question (Appendix A2). Ten of the thirteen selected participants completed the second round Delphi survey, for a 77% participation rate.

Each question from Table 4 was asked twice, once to enable participants to rate the importance and once to enable them to determine the order of when the variable is considered. Importance was rated as very important, important, neither important nor unimportant, unimportant, very unimportant, or not applicable, where participants could select a maximum of one option. The options for the order were: before I start designing the lab, at the start of the design process, in the middle of the design process, near the end of the design process, right before the first time the lab is conducted, after the first time the lab is conducted, and not applicable. Participants could select more than one option for order, to account for variable themes that may be considered at more than one stage of the design process. Finally, participants were asked the open-response question: "Is there anything you do or consider when developing a new chemistry laboratory that is not included in the items in this survey? What is it? When do you consider it, and how important is it to creating a new chemistry laboratory?"

Importance ratings of considerations made during chemistry laboratory design. Importance ratings were analyzed both by averages and by frequencies. To determine the average rating, very important (VI) was given a rating of 5, important (I) was given a rating of 4, neither important nor unimportant (N) was given a rating of 3, unimportant (U) was given a rating of 2, very unimportant (VU) was given a rating of 1, and scores of not applicable (NA) were omitted from the average. These averages are shown in Table 5, along with the frequencies for each selected item. The questions are ordered based on the average scores. Frequencies are shaded to aid in interpretation, with darker shading indicating a higher frequency. Experts generally found the variables important (average of 3.5 or higher) or neutral (average of 2.5-3.5), which supports the identification of these items as variable themes used in chemistry laboratory design. Only one variable, noise, was found to be unimportant (average of 2.5 or lower), and this variable was only mentioned by one individual in the first round. This variable may only be a concern in limited cases. This supports the inclusion of the other variables in the development of the model.

Order ratings of when particular considerations are made or sequenced during chemistry laboratory design. Order ratings were analyzed by frequencies to allow the identification of the sequence of when variables that are considered in the design process. Experts could select none, one, or more than one order for each consideration. The frequencies are shaded to aid in interpretation, with darker shading indicating a higher frequency in Table 6. The questions are also numbered, based on the order in which they were asked in the survey. The categories are: before I start designing the lab (B), at the start of the design process (S), in the middle of the design process (M), near the end of the design process (E), right before the first time the lab is conducted (L), after the first time the lab is conducted (A), and not applicable (NA).

Table 5
Frequency of Importance Ratings from Round Two of the Delphi by Question, Rated from Very Important to Very Unimportant

Rank order	Question	μ	VI	I	N	U	VU	NA
1	The amount of time needed to conduct the experiment	4.6	6	4	0	0	0	0
2	Determining appropriate goals, outcomes, and skills for the laboratory experiment	4.5	6	3	1	0	0	0
3	Developing laboratories that increase student interest or motivation	4.5	5	5	0	0	0	0
4	Determining the safety considerations, hazards, and safety equipment for an experiment	4.5	6	3	1	0	0	0
5	Determining how to inform students of the safety hazards	4.3	4	5	1	0	0	0
6	Basing the laboratory experiment on the material in lecture	4.2	2	8	0	0	0	0
7	Developing problem-solving skills	4.2	2	8	0	0	0	0
8	Planning for including experimental skills students should have at the end of a laboratory sequence or program.	4.1	3	5	2	0	0	0
9	Developing an experiment with repeatable, interpretable results	4.1	3	5	2	0	0	0
10	Testing an experiment with students, faculty (other than yourself), or teaching assistants before it is fully implemented for courses	4.1	5	2	2	1	0	0
11	Creating a laboratory handout, text, manual, data sheet, or other written material for an experiment (paper or electronic)	4.1	4	4	1	1	0	0
12	Creating instructions on how to prepare solutions, equipment, or other materials for an experiment	4.1	3	5	2	0	0	0
13	Determining the appropriate level of inquiry a student should experience for a particular experiment	4	2	6	2	0	0	0
14	Creating an instructor guide with notes, text, or lab supplements	4	3	5	1	1	0	0

15	Considering the time needed for students to prepare for an experiment	4	3	4	3	0	0	0
16	Emphasizing appropriate laboratory and technological skills based on skills needed for industry, research, or graduate school	3.9	1	7	2	0	0	0
17	Matching the difficulty of performing the experiment with student skills	3.9	3	3	4	0	0	0
18	Re-purposing existing laboratories to meet new requirements, methods, or needs	3.9	2	5	3	0	0	0
19	Determining the appropriate level of autonomy or responsibility a student should experience for a particular experiment	3.9	1	7	2	0	0	0
20	Using your experience and intuition to make design choices	3.9	3	3	4	0	0	0
21	Avoidance of toxic chemicals or wastes through the use of less toxic alternatives such as green chemistry or household chemistry	3.8	4	2	2	2	0	0
22	Determining the type of laboratory (expository, open inquiry, guided inquiry, problem- based, and student designed) appropriate to the experiment.	3.7	1	5	4	0	0	0
23	Costs or budget considerations, such as considering the number, availability, or price of laboratory equipment needed for an experiment	3.7	3	3	2	2	0	0
24	Developing materials to ensure consistency in grading, such as rubrics or keys, either within a course or between instructors	3.7	4	2	2	1	1	0
25	Gathering data about a laboratory, such as surveys, observations, student feedback, or results, to make design choices	3.6	2	4	2	2	0	0

26	Considering other individuals who may teach this laboratory experiment, such as other faculty, teaching assistants, staff, or others who may read the experiment if it is published	3.6	3	3	3	0	0	0
27	Considering the ethics of conducting the experiment	3.6	4	1	4	0	0	0
28	Addressing student misconceptions	3.4	1	3	5	1	0	0
29	Determining how much labor would be needed to prepare and support a particular experiment	3.4	1	5	2	1	1	0
30	Determining if a laboratory should be conducted individually, in pairs, or in groups	3.4	2	3	3	1	1	0
31	Creating appendices or other collections of information on how to perform common techniques or use common equipment	3.4	3	3	1	1	2	0
32	Designing to support academic honesty (preventing cheating or plagiarism)	3.3	2	3	3	1	0	1
33	Creating lists of materials for ordering and preparing for an experiment	3.3	2	3	3	0	2	0
34	Basing the design on laboratory experiments in the literature	3.2	0	5	3	1	1	0
35	Planning class time to discuss results	3.2	2	2	3	2	1	0
36	Examining the curriculum at a broad level (program, course) for gaps or needs	3.2	1	2	6	0	1	0
37	Creating materials or media that follow a consistent format throughout a course	3.2	1	4	2	2	1	0
38	Choosing a type of assessment for a particular experiment	3.1	2	2	2	3	1	0
39	Decreasing the amount of toxic chemicals or wastes through microscale techniques	3.1	2	3	1	2	2	0
40	Working with a team to develop new laboratories, such as consulting other instructors	3	0	2	6	2	0	0
41	Creating presentation materials for an experiment	3	1	2	3	4	0	0

42	Determining the amount of labor needed to perform assessments for an experiment	2.9	0	4	2	3	1	0
43	Creating or gathering media, such as videos, pictures, spectra, course sites (such as BlackBoard), and related materials	2.9	1	3	2	2	2	0
44	Considering institutional or program level accreditation	2.8	1	1	5	1	2	0
45	Developing laboratories that allow individual instructor variations in conducting laboratories	2.8	0	2	5	2	1	0
46	Creating training or guides for others who may teach this laboratory experiment	2.7	3	1	2	1	0	2
47	Considering the noise level of the room	2.3	0	1	3	4	2	0

Note: Shading indicates the frequency of responses. The darker shading indicates a larger number of responses from participants. 10 participants completed the ratings. They could only respond once per question or skip the question. Ratings were given values from Very Important = 5 to Very Unimportant = 1. Not applicable (NA) was not included in the calculation of the mean.

Table 6
Order ratings by question

#	Questions	B	S	M	E	L	A	NA
1	Basing the laboratory experiment on the material in lecture	7	4	1	1	0	0	0
2	Basing the design on laboratory experiments in the literature	4	3	1	0	0	0	2
3	The amount of time needed to conduct the experiment	2	3	3	3	0	0	1
4	Planning class time to discuss results	1	1	2	2	0	1	4
5	Planning for including experimental skills students should have at the end of a laboratory sequence or program.	4	5	1	0	0	1	0
6	Emphasizing appropriate laboratory and technological skills based on skills needed for industry, research, or graduate school	4	2	1	0	0	0	3
7	Determining appropriate goals, outcomes, and skills for the laboratory experiment	3	6	1	2	0	1	0
8	Developing laboratories that increase student interest or motivation	6	5	2	2	2	2	0
9	Matching the difficulty of performing the experiment with student skills	4	6	2	2	1	2	0
10	Addressing student misconceptions	0	1	2	3	1	3	3
11	Working with a team to develop new laboratories, such as consulting other instructors	3	4	1	1	1	1	1
12	Determining the safety considerations, hazards, and safety equipment for an experiment	4	5	4	1	1	1	0
13	Re-purposing existing laboratories to meet new requirements, methods, or needs	6	5	0	0	0	2	0
14	Determining the appropriate level of inquiry a student should experience for a particular experiment	2	3	2	4	1	3	0
15	Determining the appropriate level of autonomy or responsibility a student should experience for a particular experiment	1	1	2	5	1	3	0
16	Determining the type of laboratory (expository, open inquiry, guided inquiry, problem- based, and student designed) appropriate to the experiment.	4	3	2	3	0	2	0
17	Examining the curriculum at a broad level (program, course) for gaps or needs	3	2	1	0	0	0	3

18	Considering institutional or program level accreditation	1	0	0	0	1	1	6
19	Costs or budget considerations, such as considering the number, availability, or price of laboratory equipment needed for an experiment	4	3	2	0	2	1	0
20	Determining how much labor would be needed to prepare and support a particular experiment	1	3	4	1	3	1	1
21	Choosing a type of assessment for a particular experiment	1	1	1	3	2	2	1
22	Determining the amount of labor needed to perform assessments for an experiment	1	1	0	4	2	2	1
23	Developing materials to ensure consistency in grading, such as rubrics or keys, either within a course or between instructors	0	0	0	5	2	1	2
24	Developing laboratories that allow individual instructor variations in conducting laboratories	0	1	1	1	0	1	5
25	Designing to support academic honesty (preventing cheating or plagiarism)	0	1	0	5	2	3	1
26	Developing an experiment with repeatable, interpretable results	1	2	4	5	1	3	0
27	Developing problem-solving skills	2	6	2	3	1	3	0
28	Determining if a laboratory should be conducted individually, in pairs, or in groups	0	0	2	5	1	1	2
29	Considering the noise level of the room	0	0	0	0	1	1	7
30	Avoidance of toxic chemicals or wastes through the use of less toxic alternatives such as green chemistry or household chemistry	3	3	3	3	0	0	1
31	Decreasing the amount of toxic chemicals or wastes through microscale techniques	2	4	3	1	0	0	3
32	Determining how to inform students of the safety hazards	2	3	3	5	0	1	0
33	Using your experience and intuition to make design choices	4	5	3	2	1	1	2
34	Gathering data about a laboratory, such as surveys, observations, student feedback, or results, to make design choices	2	1	1	1	1	6	0
35	Testing an experiment with students, faculty (other than yourself), or teaching assistants before it is fully implemented for courses	0	1	1	7	2	1	0
36	Creating materials or media that follow a consistent format throughout a course	0	2	0	5	0	0	2

37	Creating a laboratory handout, text, manual, data sheet, or other written material for an experiment (paper or electronic)	0	0	2	5	1	1	1
38	Creating presentation materials for an experiment	0	0	0	3	3	0	3
39	Creating or gathering media, such as videos, pictures, spectra, course sites (such as BlackBoard), and related materials	0	1	1	2	2	0	4
40	Creating lists of materials for ordering and preparing for an experiment	0	0	2	5	1	0	1
41	Creating instructions on how to prepare solutions, equipment, or other materials for an experiment	0	0	1	7	0	0	1
42	Creating an instructor guide with notes, text, or lab supplements	0	0	1	5	1	2	2
43	Creating appendices or other collections of information on how to perform common techniques or use common equipment	0	0	0	5	2	2	2
44	Considering other individuals who may teach this laboratory experiment, such as other faculty, teaching assistants, staff, or others who may read the experiment if it is published	1	3	3	5	4	4	0
45	Considering the ethics of conducting the experiment	4	3	2	1	3	1	2
46	Creating training or guides for others who may teach this laboratory experiment	1	1	1	4	4	4	2
47	Considering the time needed for students to prepare for an experiment	0	1	3	4	2	2	1

Note: Shading indicates the frequency of responses for each option. The darker shading indicates a larger number of responses from participants. 10 participants completed the ratings. They could respond once, more than once per question, or skip the question. The categories from left to right in the table are: before I start designing the lab (B), at the start of the design process (S), in the middle of the design process (M), near the end of the design process (E), right before the first time the lab is conducted (L), after the first time the lab is conducted (A), and not applicable (NA).

All of the variables were considered by the experts at more than one time in the design process, though some patterns are apparent from Table 6. Some variables are predominantly considered at the start, the middle, or the end of the design process, while other variables are more evenly distributed across the design process. For example, question 1, "Basing the laboratory experiment on the material in lecture," was considered before the design process starts (7 selections) and at the start of the design process (4 selections), with only one selection each for the middle and end of the design process. This suggests that this variable is most important at the start of the design process, while the design is being planned. No experts selected this variable as being important late in the process (L or A).

Preliminary Model Development and Literature Review (Stage 4)

There are a few patterns that emerge in the results in Table 6, and these patterns allow the development of a procedural model of chemistry laboratory design. A procedural model is an experience-based model of the tasks involved in creating a product (Richey, Klein, & Tracey, 2011). In this case, the experts are chemistry laboratory designers who have identified the tasks involved in development of chemistry laboratory experiments.

First, these experts tended to not distinguish between variables considered before the design process and at the start of the design process. These variables involve aspects of planning, including determining the content of the laboratory from lecture, the literature, industry needs, and making major preliminary design choices. This group of considerations was identified as the "Planning" phase in the preliminary model in *Figure 3*. Elements of the planning phase share some characteristics of both the analysis and design phases of the ADDIE model, but the data from the second round survey does not allow determination of whether the experts distinguish between analysis and design as separate phases (Molenda, 2003). Planning includes elements of analysis, such as determining gaps in the curriculum and costs, and it considers elements of design, such as determining appropriate outcomes for the laboratory. A summary of this phase is included in the "Explanation of Model" that was created for inclusion in the round-three survey (Appendix A3).

The second phase of the design process involves "Development" and the variables involved in the development of the materials, experiments, and assessments. This includes variables that the experts consider in the middle and end of the design process (M and E), as seen in Table 6. This phase also includes testing the laboratory before it is first conducted to allow revision of the materials and experiments. This phase could be considered analogous to the development phase within the ADDIE model, though it includes elements of pilot testing that are more commonly seen in the implementation phase of the ADDIE model (Gagné et al., 2005).

The third phase of the design process involves "Implementation" of the laboratory designed in the previous phases. This includes determining the amount of labor needed to prepare and conduct the experiment, preparing the individuals who will conduct the experiment, and determining how the laboratory will be assessed consistently. This phase is similar to the implementation phase within the ADDIE model (Gagné et al., 2005).

The fourth phase of the design process is “Revision” which involves collection of data to adjust the complexity and style of the laboratory, preparing the laboratory to be conducted by others, and to adapt the laboratory in an iterative process. This phase is based in part on the results in Table 6, after the first time the lab is conducted (A), and it is further supported by the results from the first round of the Delphi survey, where the importance of an iterative design process was emphasized by the expert chemistry laboratory designers. This phase cycles back to the planning phase of the process, to complete the loop.

These four cyclic phases are supported by a fifth continuous phase of assessment termed the “Evaluation” phase, which involves a number of variables that are considered throughout the design process. This central phase involves student interest and motivation, determining if there is a match to student skills, evaluating problem solving, evaluating safety, and determining ethical considerations. These variables are considered throughout the design process, consisting of a process of continuous evaluation and assessment. For example, it is both important to consider keeping students safe and to ensure that students learn safety topics throughout the design process. This supports an interaction between this phase and the four other phases, indicated by the bi-directional equilibrium arrows in *Figure 3*. The arrow design is based on arrows used in reactions in chemistry. The revision phase and evaluation phase in this model share similarities with the evaluation phase within the ADDIE model (Gagné et al., 2005).

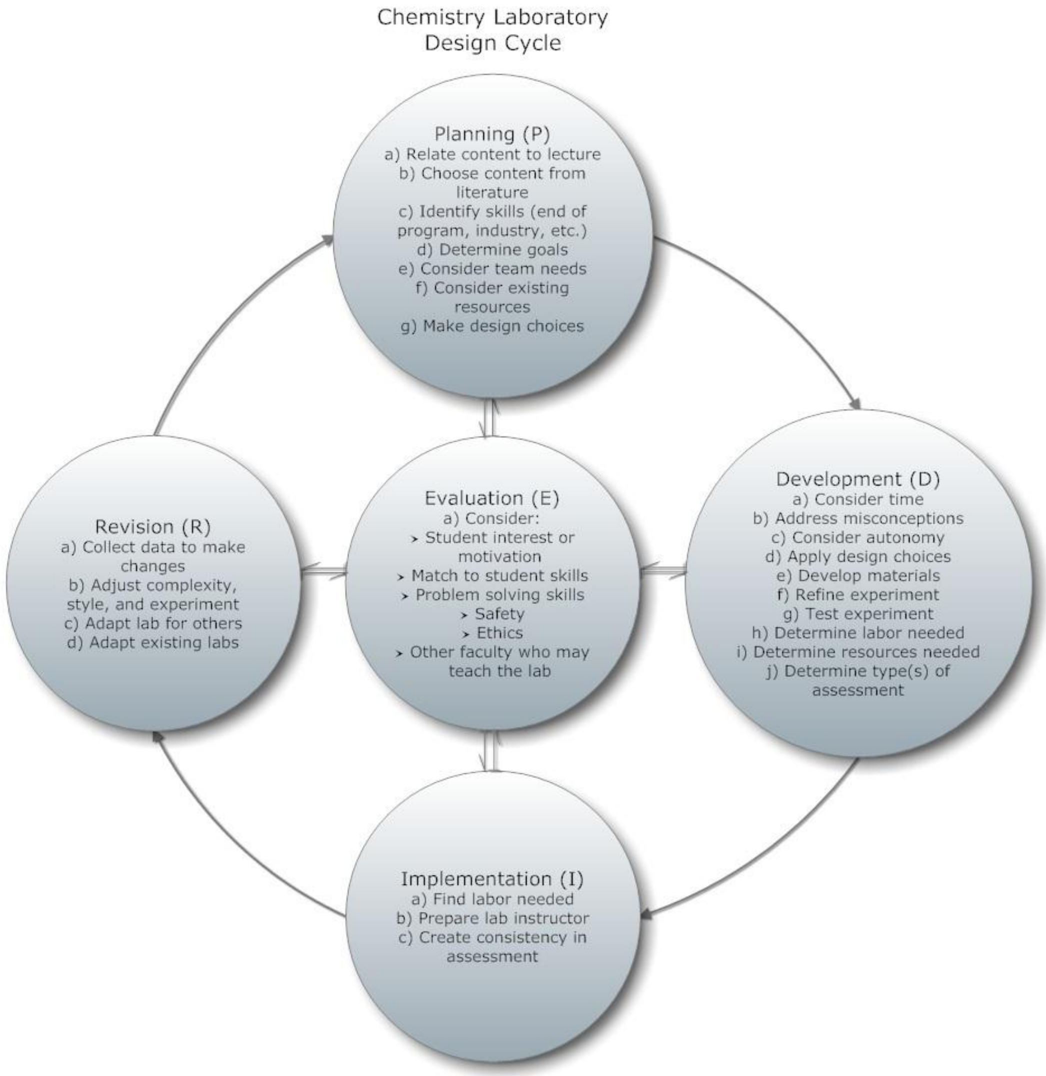

Figure 3: Preliminary model of chemistry laboratory design. This figure depicts each stage of the design process.

Explanation of Model:

P. Planning Phase

Step a) Determine the relationship of the content to the lecture and choose the appropriate relationship. How closely will the content match, and is the order important?

b) Select content from the literature.

c) Identify the skills students will need at the end of the program or course for industry, graduate school, or research.

d) Determine the goals of the laboratory.

e) Consider the needs of other individuals who may teach the lab by planning with them.

f) Consider the existing resources, such as equipment, budget, and current labs.

g) Make major design choices such as determining desired outcomes and skills and considering the type of lab needed.

D. Development Phase

a) Consider the time needed to conduct the lab and for students to prepare for lab.

b) Determine how to address possible student misconceptions.

c) Consider the appropriate level of autonomy from student-directed to explicit steps.

d) Apply the design choices to create the appropriate lab style and level of inquiry.

e) Select and develop the materials to support the lab, such as manuals, guides, and media.

f) Refine the details of the experiment.

g) Test the experiment with other faculty or students.

h) Determine the labor needed to prepare and conduct the lab.

i) Determine the resources needed, such as chemicals, glassware, and equipment.

j) Determine the type(s) of assessment for the lab

I. Implementation Phase

a) Find the support and labor needed to conduct the laboratory.

b) Prepare the instructor with manuals or training.

c) Create consistency in assessment with rubrics or other grading guides.

R. Revision Phase

a) Collect data on the lab, such as student feedback, lab results, or assessment results to guide the revision process.

b) Adjust the complexity of the lab based on the data gathered.

c) Adapt the lab to be conducted by other instructors.

d) Adapt existing labs for re-use.

E. Evaluation (Continuous process)

a) Consider the balance between each phase of the cycle (P, D, I, or R) and each of the following:

- Student interest or motivation – What motivates students? How can motivation be increased?
- Match to student skills – What skills do students have already? What do they need?
- Student problem solving skills – What skills do they possess? How can problem-solving skills be developed?
- Safety for the student or the environment – How can safety be ensured? How can the lab teach safety skills?
- Ethics of conducting experiments – Is the lab ethical to conduct? How can the lab reinforce experimental ethics?
- Other instructors who may teach the lab – What feedback can other faculty provide? What details need to be provided for the individuals who may teach the lab?

Figure 4: Preliminary explanation of model of chemistry laboratory design for round 2 of the Delphi survey.

Delphi Round Three (Stage Five)

The third round of the Delphi survey included the preliminary model (*Figure 3* and *Figure 4*) and questions to determine in what ways the preliminary model may need to be modified to make it more accurate, useful, and practical. This survey included a combination of Likert-type questions and open-response follow-up questions (Appendix A3).

Agreement ratings for evaluation of the preliminary model. Eight questions were asked using a Likert-type rating scale of strongly agree, agree, neutral, disagree, strongly disagree, or not applicable. Participants could select only one answer. These answers are listed as frequencies in Table 7. These results show that the experts agree that the model is accurate, organized appropriately, easy to understand, and useful. Though the experts agreed on the benefits of the model, these results also suggest that there may be areas of revision that could improve the model, since three was some small variation in the levels of strong agreement and agreement. Though these are relatively minor variations, they suggest the potential for improvement by minor changes to the model, such as re-ordering of steps. These possible areas of improvement are identified and refined in the open-response follow-up questions.

Responses to open-response follow-up questions to aid in refining the model. Open-response questions were used to clarify the areas in which the model could be improved. Participants could respond with multiple suggestions to each question, or they could skip the question. Analysis of the responses to each of these questions follows. Suggestions based on the order or clarification of steps within the model were determined to be minor changes, and were made based on at least one response suggesting the change. Major revisions are defined as changes to the phases or inclusion of additional material in the model, and these changes were not made unless there were at least two responses indicated the required change.

How would you change the organization of these phases? Participants suggested few changes to the overall organization of the phases or stated that they would suggest no changes. The one consistent change that was suggested was to add a statement concerning the flexibility of the model. Three experts suggest that sometimes certain parts of the model may be skipped. This suggested the inclusion of directions for the refined model.

As a result of the experts' suggestions, the following directions were added to the model:

Instructions:

The model on the following pages describes the process of designing undergraduate chemistry laboratory experiments. The first version of the model is a visual, followed by a more descriptive explanation of the process. Not all phases (bubbles) or steps (a, b, c, etc.) are used in all processes of designing all laboratories. There may also be unique considerations based on your institution, facilities, your creativity, or other considerations.

Table 7
Frequency of Agreement Ratings from Round Three of the Delphi by Question, Rated from Strongly Agree to Strongly Disagree

#	Question	SA	A	N	D	SD	NA
1	This model describes what I do when I create a new chemistry laboratory experiment.	0	9	1	0	0	1
2	The phases in this model (P, D, I, R, and E) are organized appropriately.	1	10	0	0	0	0
3	The important phases are included in this model.	4	7	0	0	0	0
4	The important steps are included within each phase of the model.	2	7	2	0	0	0
5	The steps in this model are easy to understand.	2	8	1	0	0	0
6	This model would be helpful for someone developing new chemistry laboratory experiments for the first time.	3	6	2	0	0	0
7	This model would be helpful for someone who has experience in developing chemistry laboratory experiments.	1	6	4	0	0	0
8	I plan on using this model when I develop new chemistry laboratory experiments.	4	5	2	0	0	0

Would you add any phases or steps? If so, which ones? Participants made few suggestions to add phases or steps in general. Specifically, one individual suggested adding a step clarifying the analysis of data gathered from a laboratory during the revision phase. This step was added to the model, since it fit with the data from the previous rounds of the survey. This change is highlighted in *Figures 5* and *6*. This additional step was added as the last step in the Revision phase, though it may logically be conducted earlier. No feedback was received concerning when this additional step would best fit into the Revision phase.

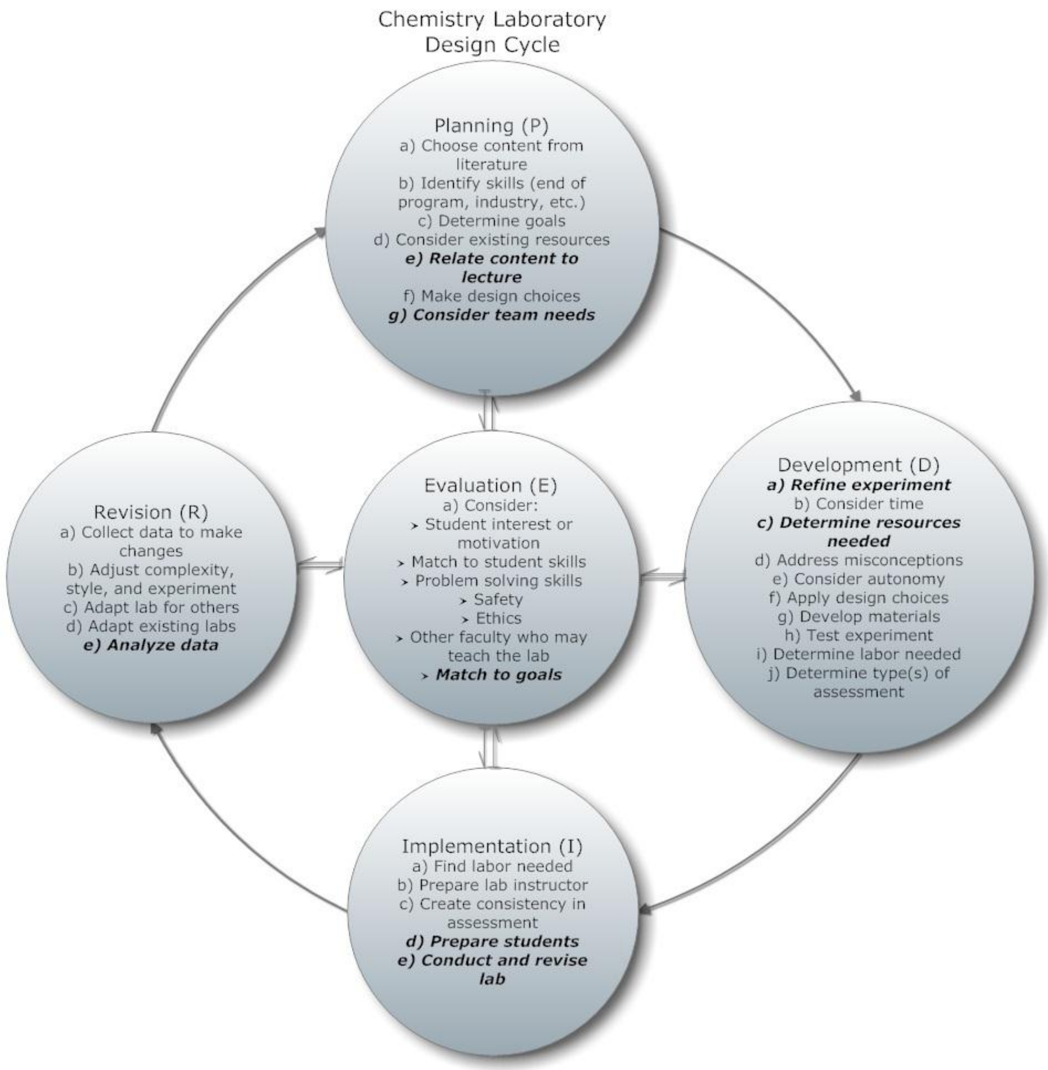

Figure 5: Revised model for interview verification stage, with changes from the preliminary model highlighted with bold and italics.

Explanation of Model:

A. Planning Phase

Step a) Select content from the literature/current research.

b) Identify the skills students will need at the end of the program or course for industry, graduate school, or research.

c) Determine the goals of the laboratory.

d) Consider the existing resources, such as equipment, budget, and current labs.

e) **Determine the relationship of the content to the lecture and choose the appropriate relationship. How closely will the content match, and is the order important?**

f) Make major design choices such as determining desired outcomes and skills and considering the type of lab needed.

g) **Consider the needs of other individuals who may teach the lab by planning with them.**

D. Development Phase

a) **Refine the details of the experiment.**

b) Consider the time needed to conduct the lab and for students to prepare for lab.

c) **Determine the resources needed, such as chemicals, glassware, and equipment.**

d) Determine how to address possible student misconceptions.

e) Consider the appropriate level of autonomy from student-directed to explicit steps.

f) Apply the design choices to create the appropriate lab style and level of inquiry.

g) Select and develop **clear, concise** materials to support the lab, such as manuals, guides, and media.

h) Test the experiment with other faculty or students.

i) Determine the labor needed to prepare and conduct the lab.

j) Determine the type(s) of assessment for the lab

I. Implementation Phase

a) Determine the support and labor needed to conduct the laboratory.

b) Prepare the instructor with manuals or training.

c) Create consistency in assessment with rubrics or other grading guides.

d) **Prepare students**

e) **Conduct and revise the laboratory as the laboratory is performed**

R. Revision Phase

a) Collect data on the lab, such as student feedback, **instructor feedback,** lab results, or assessment results to guide the revision process.

b) Adjust the complexity **and accuracy** of the lab based on the data gathered.

c) Adapt the lab to be conducted by other instructors.

d) Adapt existing labs for re-use.

e) **Analyze data gathered to determine how materials, protocols, and methods should be changed. Compare student lab results to the literature.**

E. Evaluation (Continuous process)

a) Consider the balance between each phase of the cycle (P, D, I, or R) and each of the following:

- Student interest or motivation – What motivates students? How can motivation be increased?
- Match to student skills – What skills do students have already? What do they need? How do these relate to their laboratory skills?
- Student problem solving skills – What skills do they possess? How can problem-solving skills be developed?
- Safety for the student or the environment – How can safety be ensured? How can the lab teach safety skills?
- Ethics of conducting experiments – Is the lab ethical to conduct? How can the lab reinforce experimental ethics?
- Other instructors who may teach the lab – What feedback can other faculty provide? What details need to be provided for the individuals (faculty, TA's, etc.) who may teach the lab?
- **Match to goals – Does the laboratory match the intended goals? How will it improve the quantity and quality of student learning?**

Figure 6: Revised model explanation for interview verification stage, with changes from the preliminary model highlighted with bold.

Would you remove any phases or steps? If so, which ones? Two participants suggested that some phases could be combined or may sometimes be skipped. Based on the lack of suggestions to completely remove anything from the model, no steps or phases were removed. This resulted in adding the caveat that not all of the phases or steps are used for designing all laboratories. This further supports inclusion of the instructions in the model.

How would you change the planning phase? Participants' suggestions were primarily based on clarifying the steps within the phase and changing the order of the steps. Participants suggested that basing the material on the lecture should not be first. This is because not all laboratories are matched with a corresponding lecture course. Participants suggested that it be moved to fifth in the list. Participants also suggested that considering team needs should be moved later in the list, since not all laboratories are planned in teams. These changes can be seen in *Figures 5* and *6*. All changes to the order were supported by at least one participant, and the change to the step involving the lecture was suggested by two participants.

How would you change the development phase? Participants suggested re-ordering of steps in this phase and a small clarification of one of the steps. The order of the steps was changed based on the participant feedback, and this new order can be seen in *Figures 5* and *6*. One participant noted that it was important that materials be clear and concise, and this wording clarification was added to step g in the development phase, as seen in *Figure 6*. All changes to this phase were minor, and based on one participant response.

How would you change the implementation phase? This is the first phase in which participants suggested adding steps to the phase. Two participants suggested the need to prepare students for the laboratory, and this step was added to implementation. Three participants suggested that conducting the laboratory was an essential part of this step. Adding this step also creates a progression to the revision phase, since participants noted that the first time the laboratory is conducted is when the data and feedback need to be collected that make the revision phase possible. Participants stated that revisions need to be incorporated "on the fly" to result in a successful implementation. These changes are reflected in *Figures 5* and *6*.

How would you change the revision phase? Participants suggested adding clarification to the existing steps in this phase and adding a separate step that makes it clear how the data gathered are used to revise the laboratory. Participants noted that the explanation needed to include feedback from instructors in addition to other sources of information, and that the data gathered from the laboratory could be used to modify the accuracy of the laboratory results in future iterations. Finally, three participants noted that the data need to be analyzed and used in a way that ensures that the changes to the laboratory are appropriate to the data gathered. This further supports inclusion of an additional step regarding the analysis of data in the Revision phase. These changes are reflected in *Figures 5* and *6*.

How would you change the evaluation phase/continuous process? Participants commented positively on the position of this phase. Two participants specifically suggested that this phase needs to include an evaluation of the goals and student achievement of the goals of the laboratory. This was added as a step in the model, as seen in *Figures 5* and *6*.

What would make these steps easier to understand? Participants suggested that clarification of the flexibility of the model would make it easier to understand, and this suggestion is reflected in the instructions indicated previously. One participant also suggested that additional clarification would make the steps easier to understand, and this is addressed by the clarification mentioned in each of the previous phases.

What would make this model more helpful to individuals who are new to designing chemistry laboratories? Participants suggested instructions, which were added. They also suggested that the model could be used as part of a larger discussion with individuals new to designing laboratories, it could be changed into a checklist, it could be modified to include details on how to do some of the steps, and it should emphasize testing out the laboratory for unexpected results. These changes were not made in the present model, since they were suggested by one participant each and would be major changes, but they could be incorporated if the model were used for training new laboratory designers.

How would you suggest teaching this model to individuals who are new to designing chemistry laboratories? Participants provided a number of suggestions about how to teach this model. Suggestions included: publishing it in the Journal of Chemical Education; providing new designers with an unordered list of the steps to group; having new designers develop an experiment without, then with, the model to gain appreciation; running a workshop on using the model for a simple design task; instruct individuals to keep a notebook of the tasks they complete while actually designing a laboratory; or simply providing the model as a resource.

What would make this model more helpful to individuals who have experience in designing chemistry laboratories? Participant responses to this question further supported the inclusion of instructions indicating that not all steps may apply. One participant noted that this model may be seen as a summary of general principles, rather than as a guide. One participant suggested that validation of the model with an individual from outside the field may be helpful.

How would you use this model? Mainly, participants wrote that they plan to use the model as a guide to help them consider new issues when creating new laboratories. Participants indicated that time might limit their ability to use the model fully.

Is this model accurate? If not, how could it be changed to more accurately show what you do or consider when you develop new chemistry laboratory experiments? Participants agreed that the model is accurate, though the steps may not all be followed or in the order indicated. This feedback is reflected in the instructions.

Would this model be helpful in developing new chemistry laboratory experiments? What could make it more helpful? Participants stated that the model would be helpful. One participant noted that laboratory developers should use their research work as a source for designing new laboratories.

What other changes would you suggest for this model? Participants had few additional suggestions. One participant suggested that developers should be encouraged to be creative when designing new laboratories and this clarification was added to the instructions. This suggestion supported the importance of intuition noted in previous rounds of the Delphi surveys.

Do you have any additional comments? Participants' additional comments were positive and supportive. One participant suggested that the model may apply to experiments outside of chemistry. Three participants stated that the model is a useful summary of the development of laboratories in chemistry. One of these participants also observed that the model could provide a foundation for discussing laboratory design in chemistry.

Interview Verification of the Revised Model and Creation of the Final Model (Stage Six)

The responses from the third round of the Delphi survey were used to develop a revised model of chemistry laboratory design (*Figure 7* and 8). This model was verified by interviews with three expert chemistry laboratory designers who did not participate in the previous Delphi surveys.

Demographic information collection for interview participants. Demographic information was collected on the three chemistry laboratory design experts who participated in the interviews. These data are included in Tables 1 and 2. Interview participants did not complete the surveys, so these data were gathered verbally.

Interview of three chemistry laboratory design experts for verification of the chemistry laboratory design model. Interview participants were each asked four open-ended questions regarding the model (*Figure 7* and *8*), and follow-up questions were asked based on these responses. The statements participants made are summarized by question below.

What are your impressions of this model? Participants all expressed positive impressions of the model. Positive statements included stating that the model "looks pretty good," "logical," "what I do, more or less," and "I liked the model." Two of the three interviewees also specifically mentioned ethics. One initially indicated that ethics was not important in designing labs, but later in the interview, this participant told a story about designing a particular chemistry teaching laboratory. In the middle of this story, it became clear that the story hinged on considerations of ethics, and the participant amended this earlier statement. The other participant who mentioned ethics stated, "I really like your inclusion of ethics." This participant teaches ethical data gathering methods, but had not fully considered how it applies to laboratories.

Instructions:
The model on the following pages describes the process of designing undergraduate chemistry laboratory experiments. The first version of the model is a visual, followed by a more descriptive explanation of the process. Not all phases (bubbles) or steps (a, b, c, etc.) are used in all processes of designing all laboratories. There may also be unique considerations based on your institution, facilities, your creativity, or other considerations.

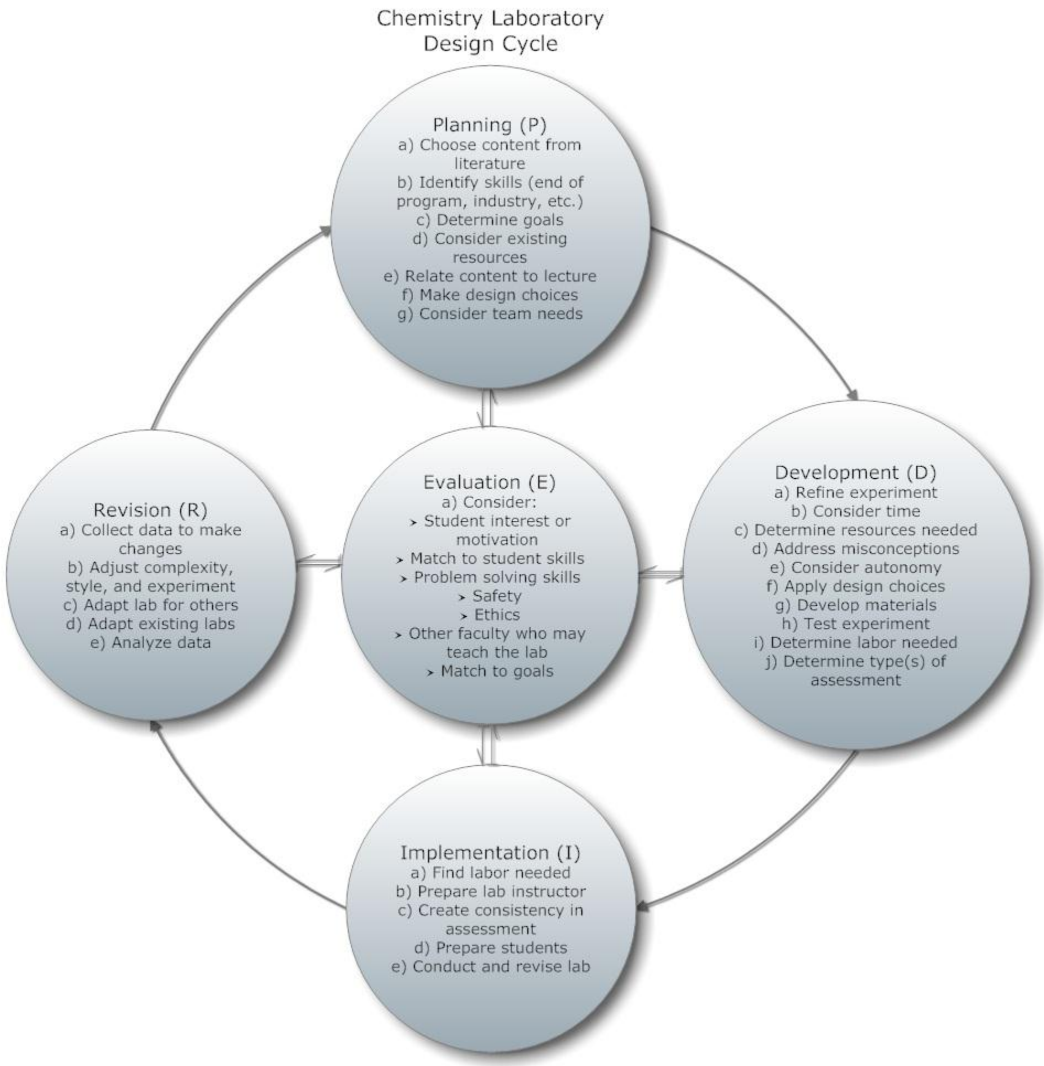

Figure 7: Revised model for interview verification stage as shown to participants.

Explanation of Model:

P. Planning Phase

Step a) Select content from the literature/current research.

b) Identify the skills students will need at the end of the program or course for industry, graduate school, or research.

c) Determine the goals of the laboratory.

d) Consider the existing resources, such as equipment, budget, and current labs.

e) Determine the relationship of the content to the lecture and choose the appropriate relationship. How closely will the content match, and is the order important?

f) Make major design choices such as determining desired outcomes and skills and considering the type of lab needed.

g) Consider the needs of other individuals who may teach the lab by planning with them.

D. Development Phase

a) Refine the details of the experiment.

b) Consider the time needed to conduct the lab and for students to prepare for lab.

c) Determine the resources needed, such as chemicals, glassware, and equipment.

d) Determine how to address possible student misconceptions.

e) Consider the appropriate level of autonomy from student-directed to explicit steps.

f) Apply the design choices to create the appropriate lab style and level of inquiry.

g) Select and develop clear, concise materials to support the lab, such as manuals, guides, and media.

h) Test the experiment with other faculty or students.

i) Determine the labor needed to prepare and conduct the lab.

j) Determine the type(s) of assessment for the lab

I. Implementation Phase

a) Determine the support and labor needed to conduct the laboratory.

b) Prepare the instructor with manuals or training.

c) Create consistency in assessment with rubrics or other grading guides.

d) Prepare students

e) Conduct and revise the laboratory as the laboratory is performed

R. Revision Phase

a) Collect data on the lab, such as student feedback, instructor feedback, lab results, or assessment results to guide the revision process.

b) Adjust the complexity **and accuracy** of the lab based on the data gathered.

c) Adapt the lab to be conducted by other instructors.

d) Adapt existing labs for re-use.

e) **Analyze data gathered to determine how materials, protocols, and methods should be changed. Compare student lab results to the literature.**

E. Evaluation (Continuous process)

a) Consider the balance between each phase of the cycle (P, D, I, or R) and each of the following:

> Student interest or motivation – What motivates students? How can motivation be increased?

> Match to student skills – What skills do students have already? What do they need? How do these relate to their laboratory skills?

> Student problem solving skills – What skills do they possess? How can problem-solving skills be developed?

> Safety for the student or the environment – How can safety be ensured? How can the lab teach safety skills?

> Ethics of conducting experiments – Is the lab ethical to conduct? How can the lab reinforce experimental ethics?

> Other instructors who may teach the lab – What feedback can other faculty provide? What details need to be provided for the individuals (faculty, TA's, etc.) who may teach the lab?

> **Match to goals – Does the laboratory match the intended goals? How will it improve the quantity and quality of student learning?**

Figure 8: Revised model for interview verification stage as shown to participants.

Would you be able to design a chemistry teaching laboratory from this model? All of the participants affirmed that they would be able to use the model. Participant statements supporting this included, "Yes, it is pretty much the model I would follow," "Pretty much the kinds of steps I use in my own lab design," and “I know for a fact that I could.” Participants noted that they may perform the steps in different order, or that there may be times when they need to use more of the steps than others. One participant mentioned that more of these steps were needed when a laboratory was designed outside the courses the participant typically teaches.

What improvements would you suggest to this model? All of the participants suggested small improvements to the model. Two of the three participants suggested that the model should include the design of pre-lab or post-lab materials. The participants defined these materials as the activities, tasks, or questions students need to complete before the laboratory session or after the laboratory session. The participants clarified that these materials can be modified to update a laboratory without changing the actual experiment performed, or to help students develop problem solving abilities.

Each participant suggested different, minor revisions. These suggestions include a greater emphasis on safety, specifying the importance of cost, adding the availability of materials, adding the need to prepare students for future courses, and moving assessments to an earlier step in the process. All of the suggested revisions were integrated into the model and are reflected in the model in *Figures 9* and *10*.

Instructions:
The model on the following pages describes the process of designing undergraduate chemistry laboratory experiments. The first version of the model is a visual, followed by a more descriptive explanation of the process. Not all phases (bubbles) or steps (a, b, c, etc.) are used in all processes of designing all laboratories. There may also be unique considerations based on your institution, facilities, your creativity, or other considerations.

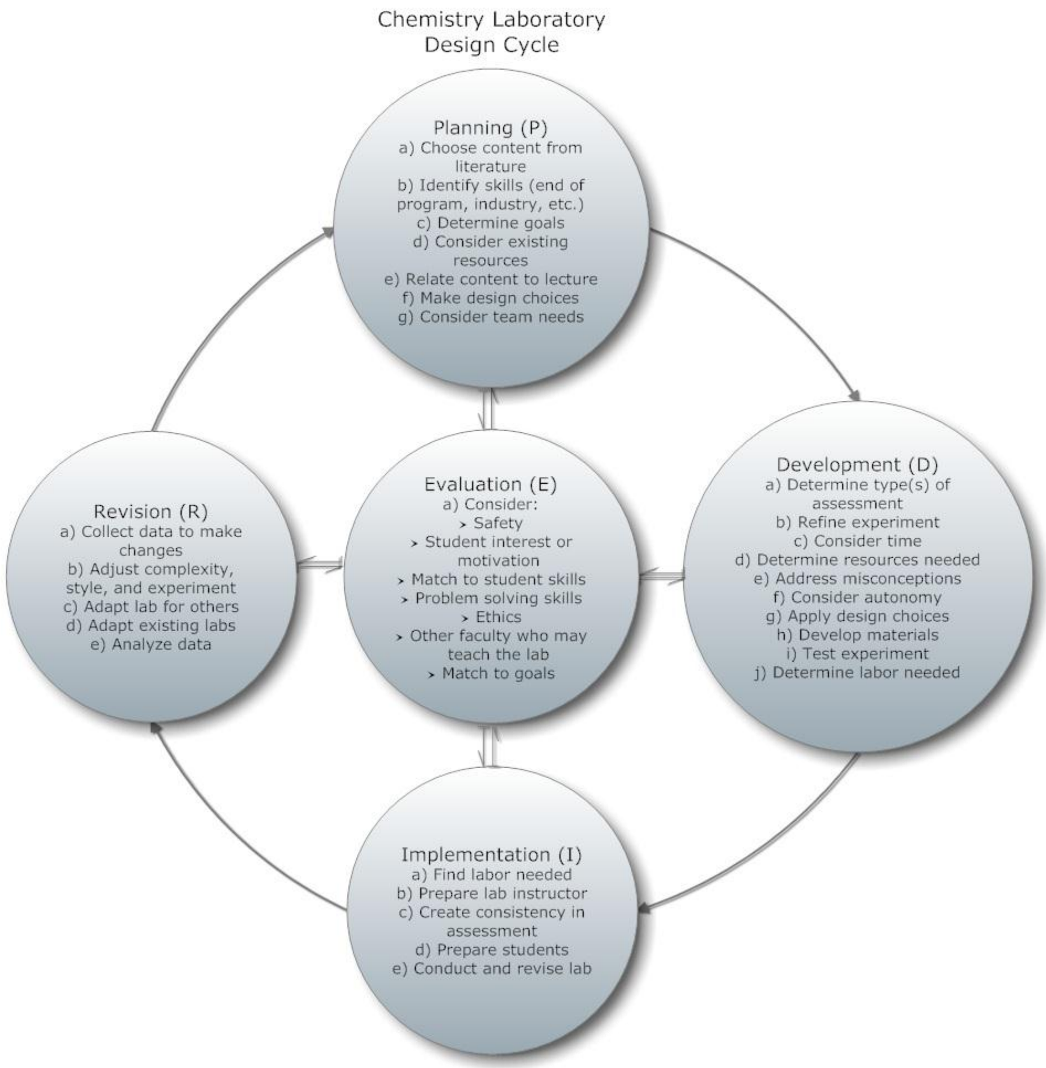

Figure 9: Final model based on results of interviews.

Explanation of Model:

P. Planning Phase

Step a) Select content from the literature/current research.

b) Identify the skills students will need at the end of the program or course for **future courses,** industry, graduate school, or research.

c) Determine the goals of the laboratory.

d) Consider the existing resources, such as equipment, budget, **costs**, **availability of materials,** and current labs.

e) Determine the relationship of the content to the lecture and choose the appropriate relationship. How closely will the content match, and is the order important?

f) Make major design choices such as determining desired outcomes and skills and considering the type of lab needed.

g) Consider the needs of other individuals who may teach the lab by planning with them.

D. Development Phase

a) **Determine the type(s) of assessment for the lab**

b) Refine the details of the experiment.

c) Consider the time needed to conduct the lab and for students to prepare for lab.

d) Determine the resources needed, such as chemicals, glassware, and equipment.

e) Determine how to address possible student misconceptions.

f) Consider the appropriate level of autonomy from student-directed to explicit steps.

g) Apply the design choices to create the appropriate lab style and level of inquiry.

h) Select and develop clear, concise materials to support the lab, such as manuals, guides, media, **pre-lab materials, and post-lab materials**.

i) Test the experiment with other faculty or students.

j) Determine the labor needed to prepare and conduct the lab.

I. Implementation Phase

a) Determine the support and labor needed to conduct the laboratory.

b) Prepare the instructor with manuals or training.

c) Create consistency in assessment with rubrics or other grading guides.

d) Prepare students

e) Conduct and revise the laboratory as the laboratory is performed

R. Revision Phase

a) Collect data on the lab, such as student feedback, instructor feedback, lab results, or assessment results to guide the revision process.

b) Adjust the complexity and accuracy of the lab based on the data gathered.

c) Adapt the lab to be conducted by other instructors.

d) Adapt existing labs for re-use.

e) Analyze data gathered to determine how materials, protocols, and methods should be changed. Compare student lab results to the literature.

E. Evaluation (Continuous process)

a) Consider the balance between each phase of the cycle (P, D, I, or R) and each of the following:

- **Safety for the student or the environment – How can safety be ensured? How can the lab teach safety skills?**
- Student interest or motivation – What motivates students? How can motivation be increased?
- Match to student skills – What skills do students have already? What do they need? How do these relate to their laboratory skills?
- Student problem solving skills – What skills do they possess? How can problem-solving skills be developed?
- Ethics of conducting experiments – Is the lab ethical to conduct? How can the lab reinforce experimental ethics?
- Other instructors who may teach the lab – What feedback can other faculty provide? What details need to be provided for the individuals (faculty, TA's, etc.) who may teach the lab?
- Match to goals – Does the laboratory match the intended goals? How will it improve the quantity and quality of student learning?

Figure 10: Final explanation of the model based on the results of the interviews, with changes in bold.

Would you consider using this model to design chemistry teaching laboratories? All of the participants would consider using the model, and they all requested the final model for future use. Participants noted that the model makes sense, and that it formalizes and enhances the process. One participant noted that individuals with an education background might already have a model like this one in mind, but chemists would not. This is because chemists are not generally trained in teaching or educational theory at the college level. This participant explained that sharing the model with them would be positive. Another participant noted that the model is a "nice list of reminders," supporting constant reflection and a cyclic process.

Chapter 4

DISCUSSION

The purpose of this study was to construct an instructional systems design model for chemistry teaching laboratory experiments at the undergraduate level. This was accomplished through examining previous research in chemistry teaching laboratory design as well as on general instructional systems design models, along with collecting data concerning practical design experiences from chemistry teaching laboratory design experts, through the Delphi method and in final follow-up interviews. The intent of this study was to identify the variables chemistry laboratory design experts consider in planning new chemistry teaching laboratory experiments, to prioritize and sequence these variables, and to construct a model based on these various results.

Identification of Variables in Design of Undergraduate Chemistry Laboratories

Possible categories of variables were identified by literature review, and questions were formulated concerning the categories of content, assessment, physical considerations, student considerations, laboratory type or style choice, teaching materials issues, experiment considerations, teacher considerations, and other possible variables. These questions were designed to be broad, to allow the collection of many different responses, as suggested in Skulmoski, Hartman, and Krahn (2007). Expert undergraduate chemistry laboratory designers completed an open-response survey with these questions, providing answers indicating specific variables. Each of these variables was examined to identify variable themes that corresponded with the expert answers. This resulted in the identification of the 47 variable themes included in Table 4.

The variable themes identified all fit within the main categories of variables identified through the literature. Most of the variable themes corresponded with more than one response from the chemistry teaching laboratory design experts. Only two variable themes were based on just one response. These variables were ethics and noise considerations, and although only one response each identified these variables, both were supported in the literature. Noise was a concern in relation to the safety equipment within a laboratory room (Lewis, 1947; Butcher et al., & Page, 1985; Saunders, 1987), while ethics are a recognized concern within chemistry instruction (Gillette, 1991; Kandel, 1994; Kovac, 1996). This supported inclusion of both noise and ethics in the second round of the survey.

Prioritization and Categorization of Variables of Chemistry Teaching Laboratory Design

The 47 variable themes identified in the first round of surveys were used to construct questions to determine the importance ratings and order of when the variables are considered in the design process.

Importance ratings. Experts rated the importance of the variable themes from very important to very unimportant, with values of five and one respectively. The importance ratings in Table 5 indicate that experts found the variable themes to be generally important or neutral, indicated by means of 2.5 or higher. Since the variable themes were based on the responses experts gave concerning what they thought was important in design, this result is not surprising. This result supports the validity of the identified variable themes. Only one variable was found to be unimportant, with a mean rating below 2.5, and this variable was noise. Since this variable was only mentioned by one expert in the first round of surveys, this suggests that noise may be a concern in limited environments, but not important for most experimental designs. Noise is also most commonly associated with safety equipment (Lewis, 1947; Butcher et al., & Page, 1985; Saunders, 1987). The high rating of 4.5 that the experts assigned to safety suggests that the safety provided by this equipment may be more important than the noise it produces in terms of undergraduate chemistry teaching laboratory design.

Order of when the variables are considered in the design process. Analysis of the order of the variables required considering variable themes that may have been considered at more than one stage of the design process. Though six categories of time were provided in the survey to determine the order of variables, the variable themes more closely fit into four main categories. Variable themes that were categorized as being considered before the design process tended to also be considered at the start of the design process, and these two time categories were condensed and labeled the Planning phase. Variable themes that had been categorized as being within the middle of the design process also tended to be considered at the end of the design process; these two categories were subsequently condensed and labeled as the Development phase. Right before the lab is conducted was labeled as the Implementation phase, and after the first time the lab is conducted was labeled as the Revision phase. Some variables were identified as occurring throughout the design process, and these variables were categorized as a separate Evaluation phase. The categorization of the variable themes within the phases of the final model is further described below.

Planning. The planning phase of the model involves a variety of considerations undergraduate chemistry teaching laboratory experts make when planning a new chemistry laboratory (*Figure 9* and *10*). This phase may involve steps that the experts indicated are completed over a very long period of time, such as choosing content from the literature. Experts indicated that they commonly collect information that may be relevant to the laboratory from their reviews of the literature for research needs. Identification of skills and goals may also occur over a long period of time, as the experts communicate with industry, graduate admissions, and other faculty to determine the skills and goals that may be missing from the existing laboratory course.

The existing resources, both monetary and material, are keys to determining what can be performed. The importance of this variable varied between the experts, possibly based on whether their institution has plenty of resources or very limited resources. Working with others also varied by expert, because the size of the chemistry departments vary from extremely large multi-faculty departments with many graduate teaching assistants to department where the expert is the only faculty member who teaches a particular laboratory.

Elements of the planning phase share some characteristics of both the analysis and design phases of the ADDIE model (Molenda, 2003). In the planning phase, experts collect and analyze information to guide design, such as information from the literature, and they make choices regarding the design.

Development. This phase has some variability in terms of when the experts complete each step, particularly in terms of assessment. Experts consider assessment at various times in the development phase, ranging from very early to very late in the process. This result mirrors the variability of when assessment is considered within the instructional design literature (Sullivan & Higgins, 1983; Wiggins & McTighe, 2006).

Refining the details of the experiment was considered an important starting point, because participants indicated that students can easily become frustrated with an experiment that does not work or that is overly complex to complete, and this is supported in the literature (Ealy & Ealy, 1994). Part of this refinement is ensuring that the laboratory can be completed in the typically time-limited laboratory class session. Experts cited testing the experiment with students or other faculty as a method of determining if the experiment will work and if the time allotted will be adequate to complete the experiment and related activities.

The resources needed for the laboratory, including material and personnel, are important in this phase. The chemicals, glassware, and other equipment that are needed for the laboratory need to be on hand, and the importance of resources is reflected in their required inclusion within laboratories submitted to the Journal of Chemical Education (American Chemical Society Publications, 2011). This means that these items need to be purchased and received if they are not already available. As noted in the interviews (*Figures 9* and *10*), some materials may not be easily available, in the case of controlled substances or specialized equipment. Some chemicals also must be synthesized immediately before an experiment, and personnel need to be available to do this. This requires planning for an appropriate number of personnel and the time to complete the preparation activities. In very small departments, one person may be designing the laboratory, setting it up, and teaching it, and these individuals indicated the need to design laboratories that could be conducted with consideration to time and staff limitations. Though these considerations are more traditionally associated with implementation activities in the ADDIE model, experts in this study identified these considerations with the development phase, versus later in the process. Responses from the interviews suggest a possible reason for inclusion of these considerations earlier in the process, since one of the interviewees noted that availability of materials limits what can be performed in the laboratory. The interviewee explained that some materials cannot be ordered, due to legal or financial limitations or due to the need to synthesize the material just before the experiment. If staff or faculty members are not available to handle ordering or synthesizing materials, then the experiment cannot be implemented.

The development phase also includes the development of the materials that allow conducting the laboratory, including the items typically including for publishing laboratory experiments (American Chemical Society Publications, 2011). This involves developing pre-lab and post-lab materials for student use, determining the specific items that will and will not be included in the laboratory methods, as well as developing manuals, guides, or media for faculty and student use. These materials need to address student misconceptions in addition to the goals and skills of the laboratory.

Implementation. At this phase, the individuals who will complete each required task to conduct the laboratory need to be identified. This may include faculty members, instructors, teaching assistants, staff members, and students, depending on the way the institution is organized. For institutions at which the tasks are completed by more than one person, training or other preparation may be needed. Rubrics or grading guides may need to be created to ensure consistency in grading. Though the development of these guides may begin in the development phase, they are refined as the laboratory is conducted to account for revisions that may occur during the implementation of the experiment.

The students need to be prepared to conduct the laboratory. This may involve providing them with the pre-lab activities to complete before they start the experiment, such as questions or readings to complete.

Finally, the laboratory is conducted with students. This is also the start of the revision process, as laboratory instructors revise the laboratory during the experiments. This may be necessary for a variety of reasons. There may be unexpected safety hazards that the instructor needs to address. There may be logistical issues, or the experiment may need slight modifications to work consistently.

Revision. The revision process relies on data collected on the laboratory experiments. These data may include student feedback, instructor feedback, experimental laboratory results versus literature results, or assessment results. The laboratory experiment is adjusted based on these data, depending on the goals of the experiment. This may involve changing the materials, protocols, or methods.

Revision may also require adapting the laboratory experiment and materials to be conducted by other instructors. For individuals at larger departments, the new laboratory experiment may be tested in a lower-enrollment session such as a summer session, and then adapted for use by the entire department. This requires that the materials be developed to be even more clear and specific.

Revision may also involve adapting existing laboratory experiments for re-use. These adaptations may be necessary due to out-of date-materials, such as old examples or a lack of application to current industry. Revision may also be necessary to allow the experiment to be published, since other individuals who would like to use the experiment "should be able to readily adapt the supporting information to their circumstances" (American Chemical Society Publications, 2011, p. 13). As noted by the experts, the revision process requires improving laboratories over long periods of time, even decades.

Evaluation. Evaluation is a continuous process of both assessment and evaluation that is constantly in balance with the other four phases. Variables in this phase need to be considered continuously throughout the process. First among these is safety. The laboratory must support as safe an environment as possible, and it must also instruct students in how to perform experiments in a safe manner. This includes both personal safety and safety for the environment, from use of appropriate safety equipment to proper disposal of waste. Clearly identifying safety issues and hazards is essential for both designing the experiment so that students learn about safety while staying safe in the laboratory, and it is important for potentially publishing experiments within the Journal of Chemical Education (American Chemical Society Publications, 2011).

Student interest and motivation need to be considered in terms of what can motivate students and how that motivation can be increased. Student skills also need to be considered in terms of what skills the students currently possess, what they need to be able to do in the future, and the relationship to laboratory-specific skills. Student problem-solving skills are one of the key skills identified as important throughout chemistry laboratories, and problem-solving skills are identified as an essential student skill within chemistry programs (American Chemical Society, 2008).

Ethics is also important to consider. This involves considering whether the laboratory is ethical to conduct and how the laboratory reinforces experimental ethics. One common example of how the experts identified ethics within the laboratory was in designing for green chemistry principles. Participants also noted the ethics of synthesizing chemicals that may be controlled or dangerous. Ethics are also an essential student skill within chemistry programs (American Chemical Society, 2008).

Other instructors who may teach the laboratory are consulted for their feedback concerning the laboratory. Considering others also ensures that all of the details needed to perform the laboratory are included. For experts who teach alone, this variable involves considering how the laboratory could be communicated to faculty at other institutions, such as through the Journal of Chemical Education.

Throughout the design process, the chemistry teaching laboratory designer determines the extent to which the laboratory experiment matches the intended goals and supports learning. This includes both how much the students learn in the laboratory and how well they learn it. This may involve elaborating on concepts in the lecture course, or it may involve learning new material in laboratory courses with no corresponding lecture.

Contribution of variables to the chemistry laboratory design preliminary model. The importance and order of the variables were used to construct a preliminary design model. The variable themes were summarized and identified as belonging to planning, development, implementation, revision, or evaluation. These summarized variables or steps were listed within the phase in no particular order, since the second round survey did not provide enough information for a more specific order (*Figure 3* and *4*). An explanation of the model (*Figure 4*) was constructed to show the steps or summarized variables with clear statements.

The explanation did not show the interaction between the phases, so a visual model was constructed to demonstrate this interaction (*Figure 3*). The four phases of planning, development, implementation, and revision corresponded with an order in time, suggesting that these four phases would be completed in order. Expert feedback from the first round of the survey suggested that the interaction between these phases was cyclical, similar to the learning cycle within the 5E model (Ansberry & Morgan, 2005). This resulted in the outer ring of the visual model.

The phase of evaluation included the variables that were considered throughout the design process. The feedback from the first survey combined with the responses from the second survey suggested that the variables in this phase are both continuous and interact with the variables in each of the other phases. This resulted in placing evaluation in the center of the model, which matches the location of evaluation of learning within the 5E model (Ansberry & Morgan, 2005). The arrows between evaluation and each of the other phases are based on the equilibrium arrows found throughout chemistry, and are similar to the arrows in the 5E model between evaluation and each other part of the cycle (Ansberry & Morgan, 2005). This type of arrow has a very specific meaning within chemistry, indicating that the interaction is bi-directional, balanced, and continuous.

Contribution of variables to the chemistry laboratory design revised model. The third and final round of surveys introduced the experts to the preliminary design model (*Figure 3* and *4*), and the experts were asked to provide their feedback on the model concerning areas requiring revision, uses of the model, and accuracy of the model. Expert feedback indicated minimal changes to the model, and these changes are indicated in *Figures 5* and *6*. The main change was the addition of instructions to clarify the limitations of the model, since the experts indicated that the model cannot show all possibilities, and not all elements of the model are used in each design. The suggested changes resulted in *Figures 7* and *8*.

There were also adjustments to the order of the steps within each phase. Since the second round survey did not allow for specific ordering, it is somewhat surprising that the experts suggested few changes to the order within each phase. Since the experts were not specifically asked to address the order of the steps within each phase, the importance of the order of the steps is difficult to evaluate.

Contribution of variables to the chemistry laboratory design final model. The revised model in *Figures 7* and *8* was verified by conducting interviews with chemistry laboratory experts. These experts met the same requirements as the experts from the Delphi survey part of the study, of publishing or being recommended by an individual who has published in the Journal of Chemical Education regarding undergraduate chemistry teaching laboratory experiments. These experts did not complete any of the previous surveys, though they were verbally asked the same demographic questions as the survey participants. The revised model was provided to each expert one week before the interview, and interviews were conducted by phone, face-to-face, or through teleconference software, based on the expert's preference.

Interviews suggested that the revised model is generally accurate, useful, and logical. Interview participants had few suggestions on how to revise the model, but one point that came up was the inclusion of pre-lab and post-lab materials in the design process. In chemistry, typically, students are required to complete tasks or assignments before or after the laboratory session, in addition to the experiments completed in the laboratory, and this was not originally included in the explanation of the model. One participant also emphasized the central focus on safety within the laboratory, leading to its movement to the first step within the evaluation phase. Another participant noted the need to consider assessment earlier in the process, and it was changed to the first step in the development phase. Other minor changes based on the interviews are reflected in *Figures 9* and *10*.

Conclusions

The goal of this study was to create a model for chemistry laboratory design that is directly applicable to the field and which aligns with the experience of expert chemistry laboratory designers. The final model and the study as a whole have some strengths and weakness, and these are based on the methods used to develop the model and feedback from the experts.

Strengths of the final chemistry laboratory design model. This model was developed with the feedback from chemistry teaching laboratory experiment design experts through the use of surveys using the Delphi method. The survey response rate was high, with the number of responses ranging from 10 to 12 out of the 13 participants that received each survey. As noted previously, homogenous participant populations allow for a sample size of 10 to 15 individuals when the Delphi method is used (Skulmoski, Hartman, & Krahn, 2007). Chemistry faculty members tend to be a homogeneous group, and this was supported by consistency within the demographic information gathered from these experts. All of the experts are currently or recently faculty members. They also demonstrated a high level of agreement on their beliefs of how students at different levels of chemistry courses learn best.

Since this model was developed based on the expertise of practitioners, it can be applied within the field. Some of the participants requested the final model so they could use it in their own design of chemistry laboratories or in training other individuals in designing new chemistry laboratories.

All of the participants were published in, or recommended by individuals published in, the Journal of Chemical Education, specifically with articles related to undergraduate chemistry laboratories. This supports the identification of these individuals as experts within undergraduate chemistry teaching laboratory design. None of these individuals have received formal training in chemistry teaching laboratory design, but they suggested that a model of this kind may be helpful in creating a way of training individuals new to chemistry laboratory teaching design. They also suggested that this model would be a good place to start for future discussion and research concerning the design of chemistry teaching laboratories.

The value of this model for future discussion and revision of how experiments are designed was highlighted within one of the interviews. One of the participants initially stated that ethics was not an important consideration in the design process. Later within the interview, the participant told a story to illustrate issues related to cost and availability of materials, but the participant realized that the story really illustrated the importance of ethics in experiment design.

Strengths of this study. The Delphi method surveys provided an iterative method for designing a chemistry teaching laboratory design model that corresponded with the experts' experiences. In addition to the excellent response rate, appropriate sample size, and high levels of agreement in the survey rounds, the Delphi method was verified by interviewing additional, external experts. These individuals met the same requirements as the survey participants, and they did not participate in the survey or see any result of the survey other than the revised model. The interviews allowed refinement of the model, including very small changes. The small number of changes and the positive feedback regarding the model verified the accuracy, usefulness, and applicability of the model.

The Delphi method can have limited generalizability if there are geographic limitations to the study sample (Skulmoski, Hartman, & Krahn, 2007). Due to the method of gathering data through electronic means, this study was able to include participants without regard to location. Participants in the survey came from multiple countries, and even though the interviews were limited to the Americas due to time differences, these participants also represented more than one country. This broad geographic sample suggests that the results may be generalizable to design in a variety of locations.

Weaknesses and limitations of the final chemistry laboratory design model. Though this model was developed with an adequate number of survey participants and validated with interviews, it was based on a small population. The participants have all directly published in the Journal of Chemical Education or were recommended by individuals who are published in the Journal of

Chemical Education. Though this is a benefit, it also limits the population further. This population may not be representative of all chemists who are experts in the design of chemistry teaching laboratory experiments. Some institutions self-publish laboratories faculty have designed or modified, and these materials are not always published in a manner that can be accessed by individuals outside the institution (Bunag & Moolick, 2009). The development of these materials may differ in some way from the development of materials intended for publication in the Journal of Chemical Education. This risk is somewhat mitigated by the significant number of laboratories the experts have designed beyond the ones published in the Journal of Chemical Education, with a typical participant publishing two to four laboratories in the Journal of Chemical Education, while half of the participants have designed at least ten experiments.

Moving assessment earlier in the development phase based on the interviews may not appropriately address when it is completed by the majority of designers, and the development of assessments may vary significantly. This is supported by the results of the second round of surveys, as well, where at least one individual identified choosing assessments occurring at every possible time in the development process. This reflects the variety of when assessments are chosen within the design literature. For example, Sullivan and Higgins (1983) place developing assessment after development of the learning activities, while Wiggins and McTighe (2006) reverse this process. The time when assessment is considered by most chemistry laboratory designers may require further study to determine how it corresponds with the literature.

This model is based on the considerations, experiences, and actions that the chemistry teaching laboratory design experts actually do when they create a new laboratory. Though this is a strength in terms of applicability, it may be a weakness in terms of efficacy of the model. There may be improvements to the process that the experts did not consider due to limitations of time or experience. As noted by the experts, none of them were trained in designing chemistry laboratories, and this may have resulted in some steps that could be more efficient.

Though the experts all found the model useful, this study did not address how useful this model will be for novice chemistry teaching laboratory designers. The experts suggested that the model would be useful for this group, but no feedback was gathered from novices at this time. Based on feedback from the experts, the novices may require a more detailed model. Checklists, examples, and other materials may need to be developed to allow the model to be used effectively by novices.

This model was developed using the Delphi method and qualitative methods. Although these methods are well received in a variety of fields such as education and health care (Skulmoski, Hartman, & Krahn, 2007), the Delphi method is not commonly used in chemistry education research. This was revealed in one of the interviews when the participant asked about how the model was developed. It was challenging to describe the Delphi method due to the participant’s lack of experience with this method. Though this method is not common within chemistry education literature, it has been used in evaluating undergraduate education, and this may aid the acceptance of the model (Melton et al., 1977).

As noted in Richey and Klein (2009), recall data regarding design tasks may not be as accurate as data gathered during the design process. The data for this study is based on recall, and individuals may have forgotten important tasks. This risk is somewhat mitigated by collecting data from multiple experts and validating the design of the model with additional experts. The Delphi method also provides participants with multiple opportunities to reflect on and correct previous responses.

In spite of these opportunities, there are important considerations that did not come up often in the early surveys, such as ethics. This important consideration was only mentioned once, yet it is an important issue within the literature concerning chemistry laboratories (Gillette, 1991; Kandel, 1994; Kovac, 1996). This is highlighted by one of the interview participants. The participant felt ethics was not important in the initial response concerning the model, but revised this evaluation when prompted to recall specific examples of design tasks. There may be additional considerations that were not mentioned that may be obvious during laboratory design.

Weaknesses and limitations of this study. A possible weakness of this model is based on the response rate for each round of the Delphi surveys. All rounds of the survey had at least one individual who did not answer the survey. Since the surveys included no identifiable information, it is impossible to determine who did not answer the survey. This means the non-participating individuals may have been different in each round.

Melton et al. (1977) highlight a possible weakness in the use of the Delphi method, in that the final findings from the Melton et al. study were not used to design the curriculum at the University of Texas at Dallas as originally intended due to two specific reasons. First, there were delays in gathering and summarizing the data that caused the results to be available only after the first year of the program was implemented. Second, faculty members at the University of Texas at Dallas were more interested in the unusual approaches suggested in the first round of the Delphi, rather than the consensus reached after the third round of the Delphi. This highlights a possible limitation of the current study, since some undergraduate chemistry teaching laboratory designers may value the unique or unusual answers that were combined to create the final model.

Future research and implications for this chemistry laboratory design model. The issue of recall could be addressed by testing this model with chemistry teaching laboratory design experts to determine if all the issues they consider are appropriately included and sequenced within the model. Experts could use the model to develop new chemistry teaching laboratory experiments, noting any considerations made that are not in the model or not in the correct place. This method would modify the existing model, without requiring the time commitment of keeping a detailed design journal. Having the experts complete a detailed design journal would be beneficial, but this population is unlikely to do so. Individuals who declined participating in the study all cited time limitations, even though this Delphi study required far less time commitment than keeping a design journal.

The chemistry teaching laboratory design model developed from this study has been verified to demonstrate the process expert chemistry teaching laboratory designers follow when creating new chemistry teaching laboratory experiments, but no data were gathered concerning the practices of novice chemistry teaching laboratory designers. This model could be strengthened by testing the model with novice chemistry teaching laboratory designers. Novices may need additional details, guides, training, or assistance to design a chemistry teaching laboratory experiment. Feedback from novices concerning whether the model is beneficial would be helpful in improving the model.

This model would also benefit from testing to determine the usability and efficacy of the model. This could include determining how easy experts and novices find the model to use, and whether they would choose to continue using it. It would also be beneficial to determine if this model effectively improves the quality of laboratory experiment produced. Quality of the laboratory experiment is a challenging concept to define, but it may be more appropriate to determine if the model is beneficial in achieving specific educational goals. For example, the American Chemical Society (2008) promotes the inclusion of elements of inquiry in laboratory courses, and this is further supported within the literature (Garnett & Garnett, 1995). Tamir and Lunetta (1978) developed materials to assess the elements of inquiry used in biology laboratories, and these materials have also been modified and used to assess chemistry laboratories (Fuhrman, Lunetta, &

Novick, 1982). This assessment could be used to determine if individuals who use the laboratory design model from this study produce materials that demonstrate more elements of inquiry than if the model is not used.

This model could also be used as a framework for studying the efficacy of the laboratory experiments produced when different design choices are made. For example, developing assessments may be more effective earlier or later in the design process and this model could provide a common framework to allow the modification of just this element of design. The laboratory experiment materials produced could then be examined to determine which order produces higher levels of inquiry. These materials could also be tested by implementation in the undergraduate chemistry teaching laboratory classroom, to determine if the elements of design translate to improved outcomes in the classroom. Ideally, optimization of the model would result in a process that chemistry teaching laboratory designers could use to improve student learning and motivation.

Optimization of the chemistry teaching laboratory design model would ideally produce a model for reliably creating new laboratory experiments to effectively aid in student learning. This would allow a more consistent research design for testing the question of whether well-designed laboratory experiments are an effective method for students to learn chemistry concepts. Though the American Chemical Society (2008) emphasizes the importance of laboratory work, previous disagreement on the efficacy of the chemistry teaching laboratory highlights the need for research on this basic question (Lippincott, 1969; Brooks, 1970; Carmody, 1935; Hawkes, 2004; Lagowski, 1999). In addition to determining if the chemistry teaching laboratory is effective, the model may assist in determining the elements of laboratory experiments that are most effective. This may also assist in identifying advantages and disadvantages of laboratory experiments, such as the negative influence of laboratories on learning in biology balanced by the positive influence on motivation in biology noted by Killermann (1998).

Implications of this methodology for model development research. Beyond the implications in the field of chemistry, this study supports the feasibility of creating models of design that are based in current practice. This contrasts with the more common construction of models based on literature review of existing research and theory (Richey & Klein, 2009). This study highlights the potential to create models of design tasks in other fields with little prior research in design models.

Participants in this study suggested that the methodology could be applied to other science fields or other levels of science education to develop models of design within those areas. They also mentioned that they would expect a high level of agreement between the design tasks in these related fields. This highlights a possible application of studies like this one in constructing models in different but related fields. These models could be used to determine tasks that are common to many fields to construct more general design models. This could be particularly helpful in developing models to aid individuals who design materials across disciplines. For example, some of the participants in this study design materials for other subjects in addition to chemistry, such as physics or biology. These individuals might benefit from a more general model of science teaching laboratory design, versus a chemistry specific model.

This method could also be used to compare models of design for different types of design, such as comparing the design of chemistry laboratories and chemistry lectures. Determining common aspects of these models could aid in training individuals to design both types of courses. This may also apply to different design tasks that are completed by individuals in other fields.

Modifications for model development research in other fields. This study could clearly be applied to model development in other areas of science, but it may also apply to model development in other fields. The best fit of this methodology would be to fields where the designer is also the instructor, individuals within the field have little or no prior training in design, the expert designers in the field are a relatively homogeneous group, there are some common elements of design within the field, and the expert designers within the field are interested and motivated. This methodology could also be modified for studies that vary on these items.

If the designer is not also the instructor, both designers and instructors may need to be included to gain a broad view of all of the tasks involved in design. Other individuals who are important to the process may also need to be included, particularly if the process is completed by a team, or completed in stages by different individuals.

If the designer or instructor has formal training in design, this could cause complications as these individuals may relate the tasks they were trained to perform within the design process, versus the tasks they actually performed. These data would benefit from additional triangulation beyond the interviews conducted in this study, such as the inclusion of actual design products or other design artifacts (Richey & Klein, 2009).

The methodology in this study relied on a homogeneous group of experts, based on the homogeneity of chemistry faculty (Neuschatz et al., 2003; Harris, & Woods, 2009). This allowed for the relatively small sample sizes of thirteen experts for the surveys and three for the interviews. In fields with more diversity, larger sample sizes would be necessary. These larger sample sizes may require modification of the questions asked in the Delphi surveys to allow for the amount of time required to analyze the responses (Skulmoski, Hartman, & Krahn, 2007). A large sample size may make broad questions, such as those asked in the first round of the Delphi survey for this study, impractical.

The Delphi method is essentially a method of arriving at a consensus, and thus it would be difficult to use this method in a field where none exists (Skulmoski, Hartman, & Krahn, 2007). It is important to distinguish between consensus in terms of design tasks and consensus in terms of what the appropriate choices are for those design tasks. For this study, participants demonstrated a high level of agreement on the variables they considered when designing experiments, but they disagreed on the appropriate choices for addressing those variables. If there are no common elements of design within a field, this method will not result in a design model. Lack of a common design model may be helpful in revealing additional information regarding the field.

Finally, this method relies on the participation of motivated and interested experts in developing the model. This response rate for each round of the surveys in this study was very high, ranging from 77% to 92% for the surveys, and this allowed for a small participant population. A less motivated or interested group would be expected to result in a lower response rate, and this would require a larger participant group (Bruggen, Wetzels, de Ruyter, & Schillewaert, 2011). Lower motivation and interest in the study may also suggest issues with the applicability of the results. Melton et al. (1977) highlights the risk of conducting Delphi surveys when there is low interest in certain aspects of the results. In the case of Melton et al. (1977), the institution may have derived equivalent benefit from conducting a single round of Delphi surveys to identify unusual aspects, versus conducting three rounds.

Limitations of the use of the methodology from this study for model development research. With modifications, this method could be used for model development within a wide variety of fields. Due to the lack of generalizability of the results of the Delphi method (Skulmoski, Hartman, & Krahn, 2007), the results of this type of study are field-specific and further limited by the expert population. Modifying the method may allow it to be applied in different types of contexts, but it should be used with caution to ensure development of an appropriately supported model.

This method can also be time-intensive, and this may limit its usefulness in developing urgently needed models or addressing urgent design questions. Results of Delphi surveys that are received late may no longer be useful (Melton et al., 1977). This limitation may also be a challenge in fields that are changing rapidly.

Summary of implications of the model and methods. This study demonstrates that model development is feasible based on practitioner experience within focused fields. Though there are significant limitations to this methodology, it has the potential for use in different fields within science and beyond.

The model developed in this study could be used to investigate both the processes and results of undergraduate chemistry teaching laboratory design. This may result in improved training of designers, improved methods of designing experiments, or improved student outcomes. The model may also be helpful in guiding development of experiments to meet particular needs. Further research on the usability and efficacy of the model is needed to evaluate its possible impact. High participant interest in the results of this study suggests that expert chemistry laboratory designers will be interested in using this model for development of new experiments and training of novice designers.

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APPENDIX A1

DELPHI ROUND 1 SURVEY

Chemistry laboratories, part 1

Demographics

1) Please select your highest degree completed:

( ) Bachelor's degree

( ) Master's degree

( ) Doctoral degree

( ) Other (please specify):: _________________

2) Major of highest degree:

( ) Chemistry, any specialization

( ) Other science or engineering discipline

( ) Non-science or engineering discipline

3) Type of institution where you teach or design laboratories or have most recently taught or designed laboratories:

( ) 2-year college

( ) 4-year college, no chemistry graduate program

( ) 4-year college, with a chemistry graduate program

4) Level of undergraduate chemistry courses of any type you have taught (select all that apply):

[ ] First year

[ ] Second year

[ ] Third year

[ ] Fourth year

5) Years of teaching undergraduate chemistry laboratories:

( ) 0-2 years completed

( ) 3-5 years completed

( ) 6-10 years completed

( ) More than 10 years

6) Number of undergraduate chemistry laboratory experiments you have designed that have been used in the laboratory classroom:

( ) 0-3 experiments

( ) 4-7 experiments

( ) 7-10 experiments

( ) More than 10 experiments

7) What training, if any did you complete on how to design or modify new chemistry laboratory experiments?

8) What part of this spectrum would best fit the way you believe students learn best at each level of chemistry laboratory?

	Everything students learn needs to be told to them directly by the instructor or book such as with laboratories with detailed steps.	Most of what students learn needs to be told to them directly.	There should be an even balance of students being told directions and completing their own planning.	Most of what students learn should be planned by the students.	Students need to discover everything they learn, such as with laboratories planned and conducted entirely by the students.
First Year	( )	( )	( )	( )	( )
Second Year	( )	( )	( )	( )	( )
Third Year	( )	( )	( )	( )	( )
Fourth Year	( )	( )	( )	( )	( )

Curriculum

As you complete these questions, think about how you design laboratory experiments for undergraduate classes. It may help to also think about how you created a specific laboratory experiment recently.
Definitions to keep in mind while completing the survey:

- **Laboratory experiment – This refers to an experiment performed in a laboratory classroom by undergraduate students.**
- **Laboratory facilities – This refers to the equipment, lab room, support areas, hallways, or any other facility details that may influence the laboratory environment.**
- **Chemical experiment – This refers to the actual experimental methods or procedures used in a laboratory experiment.**

9) How do you decide what chemistry content a new laboratory experiment will include?

10) How do you decide what outcomes or competencies students need to be able to complete by the end of a laboratory? Essentially, how do you decide what students need to be able to do?

11) What, if any, professional or accreditation guidelines do you consider when you design a new laboratory experiment?

12) How do you determine where a particular laboratory will fit into the sequence of a course?

Assessment

13) How do you assess students in the laboratory (reports, worksheets, written exams, practical exams, etc.)?

14) How do you choose the type of assessment(s)?

15) How do you assess the success of a specific laboratory experiment?

Non-personnel issue

16) How do the existing laboratory facilities influence your laboratory experiment designs?

17) What aspects of safety for individuals in the laboratory and safety for the environment do you consider when designing laboratory experiments?

18) What time and space limitations do you consider when designing laboratory experiments and how do those influence your laboratory experiment designs?

19) How do non-personnel costs (anything but faculty and staff) influence your laboratory experiment designs?

Student information

20) What information about students do you gather when designing a laboratory experiment?

21) How do you gather this information?

22) How does information about the students influence your laboratory experiment designs?

Experiment types

23) What types of laboratory experiments do you design? Examples of laboratory experiment types include: expository, open inquiry, guided inquiry, and problem- based. Please, include a brief explanation of the type.

24) How do you decide what type of laboratory experiment to design?

Materials and media

25) What types of written materials or media, if any, do you create for student use when you design laboratory experiments?

26) What types of written materials or media, if any, do you create for teacher or faculty use when you design laboratory experiments?

27) What types of written materials or media, if any, do you create for staff use when you design laboratory experiments?

28) How do you decide what types of information to include in written laboratory materials?

29) How do you format or organize this information?

Experiments

30) How do you choose and test chemical experiments or procedures that you plan to incorporate into your laboratory experiment designs?

31) What issues do you consider when planning the chemical experiment or procedure?

32) When you design a chemistry laboratory experiment, who will typically be directly supervising the students in the laboratory room?

33) How do you modify laboratory experiments based on who will teach them?

34) Are there any issues that you consider when designing a laboratory experiment that have not been addressed? If yes, please describe them.

Thank You!

Thank you for completing the first survey for this study. You will be contacted in the next couple weeks about the second survey for this study. Your continued participation is critical to this study, so we appreciate your help.

APPENDIX A2

DELPHI ROUND 2 SURVEY

Chemistry laboratories, part 2

Importance

As you complete these questions, think about how you design laboratory experiments for undergraduate classes. It may help to also think about how you would create a specific laboratory, if you were asked to do so today. What would you need to do, and in what order?
Definitions to keep in mind while completing the survey:

- **Laboratory experiment – This refers to an experiment performed in a laboratory classroom by undergraduate students.**
- **Laboratory facilities – This refers to the equipment, lab room, support areas, hallways, or any other facility details that may influence the laboratory environment.**
- **Chemical experiment – This refers to the actual experimental methods or procedures used in a laboratory experiment.**

1) Please, select the appropriate response, based on how important the item is when you develop new chemistry laboratory experiments

	Very Important	**Important**	**Neither Important nor Unimportant**	**Unimportant**	**Very Unimportant**	**Not Applicable**
Basing the laboratory experiment on the material in **lecture**	( )	( )	( )	( )	( )	( )
Basing the design on laboratory experiments in the **literature**	( )	( )	( )	( )	( )	( )
The amount of **time** needed to **conduct** the experiment	( )	( )	( )	( )	( )	( )
Planning class time to **discuss results**	( )	( )	( )	( )	( )	( )
Planning for including **experimental skills** students should have at the end of a laboratory	( )	( )	( )	( )	( )	( )

sequence or program.						
Emphasizing appropriate **laboratory and technological skills** based on skills needed for **industry, research, or graduate school**	( )	( )	( )	( )	( )	( )
Determining appropriate **goals, outcomes, and skills** for the laboratory experiment	( )	( )	( )	( )	( )	( )
Developing laboratories that increase student **interest or motivation**	( )	( )	( )	( )	( )	( )
Matching the **difficulty of performing** the experiment with **student skills**	( )	( )	( )	( )	( )	( )
Addressing **student misconceptions**	( )	( )	( )	( )	( )	( )
Working **with a team** to develop new laboratories, such as consulting other instructors	( )	( )	( )	( )	( )	( )
Determining the **safety** considerations, hazards, and safety equipment for an experiment	( )	( )	( )	( )	( )	( )
Re-purposing existing laboratories to meet new requirements, methods, or needs	( )	( )	( )	( )	( )	( )
Determining the appropriate **level**	( )	( )	( )	( )	( )	( )

of inquiry a student should experience for a particular experiment						
Determining the appropriate level of **autonomy or responsibility** a student should experience for a particular experiment	( )	( )	( )	( )	( )	( )
Determining the **type of laboratory** (expository, open inquiry, guided inquiry, problem- based, and student designed) appropriate to the experiment.	( )	( )	( )	( )	( )	( )
Examining the curriculum at a **broad level** (program, course) for gaps or needs	( )	( )	( )	( )	( )	( )
Considering institutional or program level **accreditation**	( )	( )	( )	( )	( )	( )
Costs or budget considerations, such as considering the number, availability, or price of laboratory equipment needed for an experiment	( )	( )	( )	( )	( )	( )
Determining **how much labor** would be needed **to prepare and support** a particular experiment	( )	( )	( )	( )	( )	( )
Choosing a **type**	( )	( )	( )	( )	( )	( )

of assessment for a particular experiment						
Determining the **amount of labor** needed to perform **assessments** for an experiment	( )	( )	( )	( )	( )	( )
Developing materials to ensure **consistency in grading**, such as rubrics or keys, either within a course or between instructors	( )	( )	( )	( )	( )	( )
Developing laboratories that allow **individual instructor variations** in conducting laboratories	( )	( )	( )	( )	( )	( )

Importance

2) Please, select the appropriate response, based on how important the item is when you develop new chemistry laboratory experiments

	Very Important	**Important**	**Neither Important nor Unimportant**	**Unimpor tant**	**Very Unimportan t**	**Not Applicable**
Designing to support **academic honesty** (preventing cheating or plagiarism)	( )	( )	( )	( )	( )	( )
Developing an experiment with **repeatable,**	( )	( )	( )	( )	( )	( )

interpretable results						
Developing **problem-solving skills**	( )	( )	( )	( )	( )	( )
Determining if a laboratory should be conducted **individually, in pairs, or in groups**	( )	( )	( )	( )	( )	( )
Considering the **noise level** of the room	( )	( )	( )	( )	( )	( )
Avoidance of toxic chemicals or wastes through the use of less toxic alternatives such as **green chemistry or household chemistry**	( )	( )	( )	( )	( )	( )
Decreasing the amount of toxic chemicals or wastes through **microscale techniques**	( )	( )	( )	( )	( )	( )
Determining how to **inform students of the safety hazards**	( )	( )	( )	( )	( )	( )
Using your **experience and intuition** to make design	( )	( )	( )	( )	( )	( )

choices						
Gathering **data about a laboratory**, such as surveys, observations, student feedback, or results, to make design choices	( )	( )	( )	( )	( )	( )
Testing an experiment with students, faculty (other than yourself), or teaching assistants before it is fully implemented for courses	( )	( )	( )	( )	( )	( )
Creating materials or media that follow a **consistent format** throughout a course	( )	( )	( )	( )	( )	( )
Creating a **laboratory handout, text, manual, data sheet, or other written material for an experiment** (paper or electronic)	( )	( )	( )	( )	( )	( )
Creating **presentation materials** for an experiment	( )	( )	( )	( )	( )	( )
Creating or gathering	( )	( )	( )	( )	( )	( )

media, such as videos, pictures, spectra, course sites (such as BlackBoard) , and related materials						
Creating **lists of materials** for ordering and preparing for an experiment	( )	( )	( )	( )	( )	( )
Creating **instructions on how to prepare** solutions, equipment, or other materials for an experiment	( )	( )	( )	( )	( )	( )
Creating an **instructor guide** with notes, text, or lab supplements	( )	( )	( )	( )	( )	( )
Creating **appendices** or other collections of information on how to perform common techniques or use common equipment	( )	( )	( )	( )	( )	( )
Considering **other individuals** who may teach this laboratory experiment, such as other	( )	( )	( )	( )	( )	( )

faculty, teaching assistants, staff, or others who may read the experiment if it is published						
Considering the **ethics** of conducting the experiment	( )	( )	( )	( )	( )	( )
Creating **training or guides for others** who may teach this laboratory experiment	( )	( )	( )	( )	( )	( )
Considering the time needed for **students to prepare** for an experiment	( )	( )	( )	( )	( )	( )

Time

3) Please, select the approximate time in the process of creating new chemistry laboratory experiments when you consider the items below (you may select more than one time, if applicable):

	Before I start designing the lab	**At the start of the design process**	**In the middle of the design process**	**Near the end of the design process**	**Right before the first time the lab is conducted**	**After the first time the lab is conducted**	**Not applicable**
Basing the laboratory experiment on the material in **lecture**	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Basing the design on laboratory experiments	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]

in the **literature**							
The amount of **time** needed to **conduct** the experiment	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Planning class time to **discuss results**	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Planning for including **experimental skills** students should have at the end of a laboratory **sequence or program.**	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Emphasizing appropriate **laboratory and technological skills** based on skills needed for **industry, research, or graduate school**	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Determining appropriate **goals, outcomes, and skills** for the laboratory experiment	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Developing laboratories that increase student **interest or motivation**	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Matching the **difficulty of performing**	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]

the experiment with **student skills**							
Addressing **student misconceptions**	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Working **with a team** to develop new laboratories, such as consulting other instructors	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Determining the **safety** considerations, hazards, and safety equipment for an experiment	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Re-purposing existing laboratories to meet new requirements, methods, or needs	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Determining the appropriate **level of inquiry** a student should experience for a particular experiment	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Determining the appropriate level of **autonomy or responsibility** a student	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]

should experience for a particular experiment							
Determining the **type of laboratory** (expository, open inquiry, guided inquiry, problem-based, and student designed) appropriate to the experiment.	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Examining the curriculum at a **broad level** (program, course) for gaps or needs	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Considering institutional or program level **accreditation**	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Costs or budget considerations, such as considering the number, availability, or price of laboratory equipment needed for an experiment	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Determining **how much labor** would be needed **to**	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]

prepare and support a particular experiment							
Choosing a **type of assessment** for a particular experiment	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Determining the **amount of labor** needed to perform **assessments** for an experiment	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Developing materials to ensure **consistency in grading**, such as rubrics or keys, either within a course or between instructors	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Developing laboratories that allow **individual instructor variations** in conducting laboratories	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]

Time

4) Please, select the approximate time in the process of creating new chemistry laboratory experiments when you consider the items below (you may select more than one time, if applicable):

	Before I start designing	**At the start of the**	**In the middle of the**	**Near the end of the**	**Right before the first time**	**After the first time the lab is**	**Not applicable**

	the lab	**design process**	**design process**	**design process**	**the lab is conducted**	**conducted**	
Designing to support **academic honesty** (preventing cheating or plagiarism)	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Developing an experiment with **repeatable, interpretable results**	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Developing **problem-solving skills**	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Determining if a laboratory should be conducted **individually, in pairs, or in groups**	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Considering the **noise level** of the room	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Avoidance of toxic chemicals or wastes through the use of less toxic alternatives such as **green chemistry or household chemistry**	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Decreasing the amount of toxic chemicals	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]

or wastes through **microscale techniques**							
Determining how to **inform students of the safety hazards**	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Using your **experience and intuition** to make design choices	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Gathering **data about a laboratory**, such as surveys, observations, student feedback, or results, to make design choices	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Testing an experiment with students, faculty (other than yourself), or teaching assistants before it is fully implemented for courses	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Creating materials or media that follow a **consistent format** throughout a course	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]

Creating a **laboratory handout, text, manual, data sheet, or other written material for an experiment** (paper or electronic)	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Creating **presentation materials** for an experiment	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Creating or gathering **media**, such as videos, pictures, spectra, course sites (such as BlackBoard), and related materials	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Creating **lists of materials** for ordering and preparing for an experiment	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Creating **instructions on how to prepare** solutions, equipment, or other materials for an experiment	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Creating an	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]

instructor guide with notes, text, or lab supplements							
Creating **appendices** or other collections of information on how to perform common techniques or use common equipment	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Considering **other individuals** who may teach this laboratory experiment, such as other faculty, teaching assistants, staff, or others who may read the experiment if it is published	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Considering the **ethics** of conducting the experiment	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Creating **training or guides for others** who may teach this laboratory experiment	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
Considering the time	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]

needed for **students to prepare** for an experiment							

Additional information

5) Is there anything you do or consider when developing a new chemistry laboratory that is not included in the items in this survey? What is it? When do you consider it, and how important is it to creating a new chemistry laboratory?

Thank You!

Thank you for completing the second survey for this study. You will be contacted in the next couple weeks about the final survey for this study. Your continued participation is critical to this study, so we appreciate your help.

APPENDIX A3

DELPHI ROUND 3 SURVEY

Chemistry laboratories, part 3

Page One

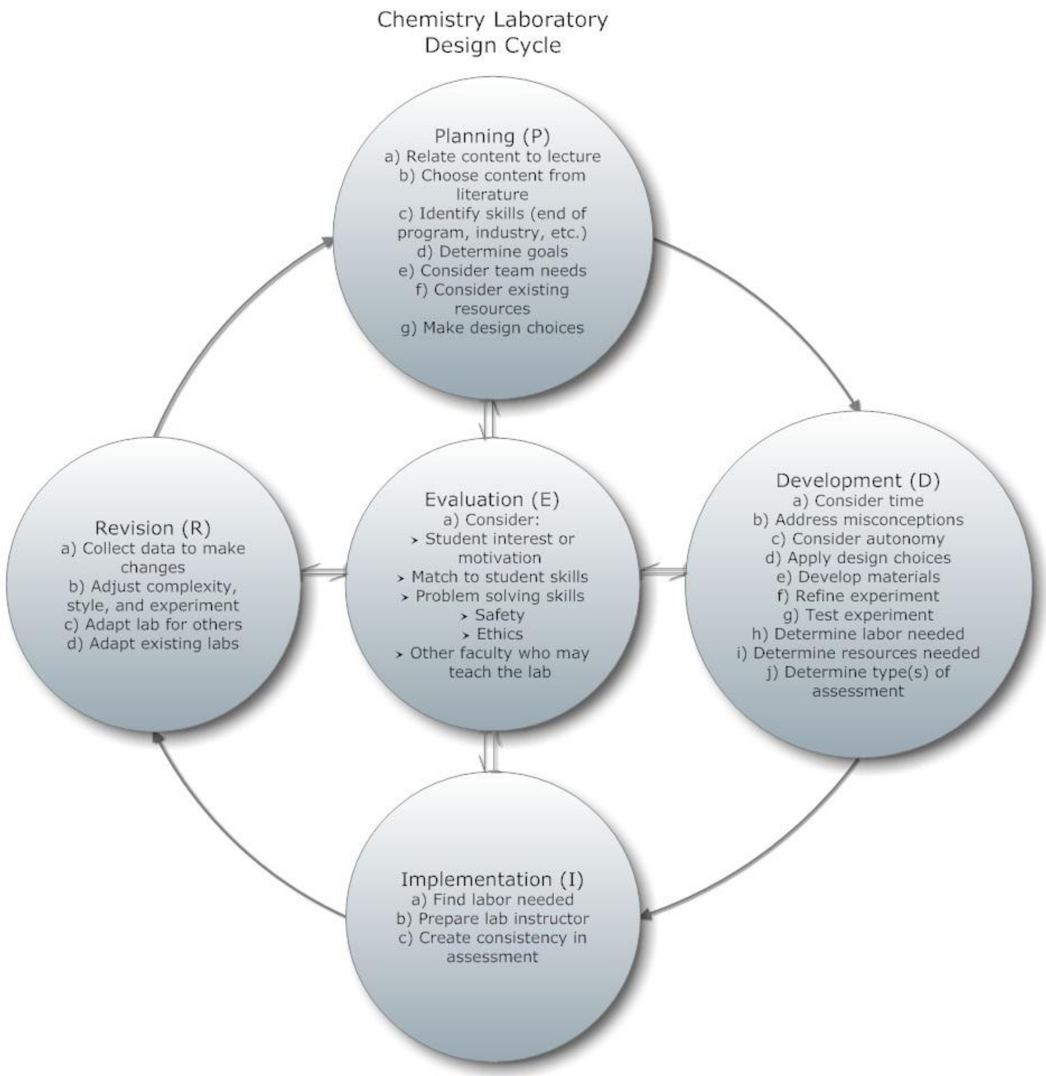
Definitions to keep in mind while completing the survey:

• Laboratory experiment – This refers to an experiment performed in a laboratory classroom by undergraduate students.

• Laboratory facilities – This refers to the equipment, lab room, support areas, hallways, or any other facility details that may influence the laboratory environment.

• Chemical experiment – This refers to the actual experimental methods or procedures used in a laboratory experiment.

Please, examine this visual model and explanation, and consider the model as you answer the questions below:


Chemistry Laboratory
Design Cycle
Planning (P)
a) Relate content to lecture
b) Choose content from literature
c) Identify skills (end of program, industry, etc.)
d) Determine goals
e) Consider team needs
f) Consider existing resources
g) Make design choices
Revision (R)
a) Collect data to make changes
b) Adjust complexity, style, and experiment
c) Adapt lab for others
d) Adapt existing labs
Evaluation (E)
a) Consider:
› Student interest or motivation
› Match to student skills
› Problem solving skills
› Safety
› Ethics
› Other faculty who may teach the lab
Development (D)
a) Consider time
b) Address misconceptions
c) Consider autonomy
d) Apply design choices
e) Develop materials
f) Refine experiment
g) Test experiment
h) Determine labor needed
i) Determine resources needed
j) Determine type(s) of assessment
Implementation (I)
a) Find labor needed
b) Prepare lab instructor
c) Create consistency in assessment

Explanation of Model:

P. Planning Phase

Step a) Determine the relationship of the content to the lecture and choose the appropriate relationship. How closely will the content match, and is the order important?

b) Select content from the literature.

c) Identify the skills students will need at the end of the program or course for industry, graduate school, or research.

d) Determine the goals of the laboratory.

e) Consider the needs of other individuals who may teach the lab by planning with them.

f) Consider the existing resources, such as equipment, budget, and current labs.

g) Make major design choices such as determining desired outcomes and skills and considering the type of lab needed.

D. Development Phase

a) Consider the time needed to conduct the lab and for students to prepare for lab.

b) Determine how to address possible student misconceptions.

c) Consider the appropriate level of autonomy from student-directed to explicit steps.

d) Apply the design choices to create the appropriate lab style and level of inquiry.

e) Select and develop the materials to support the lab, such as manuals, guides, and media.

f) Refine the details of the experiment.

g) Test the experiment with other faculty or students.

h) Determine the labor needed to prepare and conduct the lab.

i) Determine the resources needed, such as chemicals, glassware, and equipment.

j) Determine the type(s) of assessment for the lab

I. Implementation Phase

a) Find the support and labor needed to conduct the laboratory.

b) Prepare the instructor with manuals or training.

c) Create consistency in assessment with rubrics or other grading guides.

R. Revision Phase

a) Collect data on the lab, such as student feedback, lab results, or assessment results to guide the revision process.

b) Adjust the complexity of the lab based on the data gathered.

c) Adapt the lab to be conducted by other instructors.

d) Adapt existing labs for re-use.

E. Evaluation (Continuous process)

a) Consider the balance between each phase of the cycle (P, D, I, or R) and each of the following:

- Student interest or motivation – What motivates students? How can motivation be increased?
- Match to student skills – What skills do students have already? What do they need?
- Student problem solving skills – What skills do they possess? How can problem-solving skills be developed?
- Safety for the student or the environment – How can safety be ensured? How can the lab teach safety skills?
- Ethics of conducting experiments – Is the lab ethical to conduct? How can the lab reinforce experimental ethics?
- Other instructors who may teach the lab – What feedback can other faculty provide? What details need to be provided for the individuals who may teach the lab?

1) This model describes what I do when I create a new chemistry laboratory experiment.

( ) Strongly agree

( ) Agree

( ) Neutral

( ) Disagree

( ) Strongly disagree

( ) Not Applicable

2) The phases in this model (P, D, I, R, and E) are organized appropriately.

( ) Strongly agree

( ) Agree

( ) Neutral

( ) Disagree

( ) Strongly disagree

( ) Not Applicable

How would you change the organization of these phases?

____

3) The important phases are included in this model.

( ) Strongly agree

( ) Agree

( ) Neutral

( ) Disagree

( ) Strongly disagree

( ) Not Applicable

4) The important steps are included within each phase of the model.

( ) Strongly agree

( ) Agree

( ) Neutral

( ) Disagree

( ) Strongly disagree

( ) Not Applicable

Would you add any phases or steps? If so, which ones?

____

Would you remove any phases or steps? If so, which ones?

____

How would you change the planning phase?

____

How would you change the development phase?

____

How would you change the implementation phase?

____

How would you change the revision phase?

____

How would you change the evaluation phase/continuous process?

____

5) The steps in this model are easy to understand.

( ) Strongly agree

( ) Agree

( ) Neutral

( ) Disagree

( ) Strongly disagree

( ) Not Applicable

What would make these steps easier to understand?

____

6) This model would be helpful for someone developing new chemistry laboratory experiments for the first time.

( ) Strongly agree

( ) Agree

( ) Neutral

( ) Disagree

( ) Strongly disagree

( ) Not Applicable

What would make this model more helpful to individuals who are new to designing chemistry laboratories?

How would you suggest teaching this model to individuals who are new to designing chemistry laboratories?

7) This model would be helpful for someone who has experience in developing chemistry laboratory experiments.

( ) Strongly agree

( ) Agree

( ) Neutral

( ) Disagree

( ) Strongly disagree

( ) Not Applicable

What would make this model more helpful to individuals who are have experience in designing chemistry laboratories?

8) I plan on using this model when I develop new chemistry laboratory experiments.

( ) Strongly agree

( ) Agree

( ) Neutral

( ) Disagree

( ) Strongly disagree

( ) Not Applicable

9) How would you use this model?

10) Is this model accurate? If not, how could it be changed to more accurately show what you do or consider when you develop new chemistry laboratory experiments?

11) Would this model be helpful in developing new chemistry laboratory experiments? What could make it more helpful?

12) What other changes would you suggest for this model?

13) Do you have any additional comments?

Thank You!

Thank you for taking this final survey. Your response is very important to us and to this research. Copies of the final model will be available at the end of the study, by request.

APPENDIX B

ARIZONA STATE UNIVERSITY

INSTITUTIONAL REVIEW BOARD

EXEMPT STATUS

To:	Wilhelmina Savenye ED 438E (F
From:	Mark Roosa, Chair Soc Beh IRB
Date:	12/23/2011
Committee Action:	**Exemption Granted**
IRB Action Date:	12/23/2011
IRB Protocol #:	1112007209
Study Title:	Construction of an Instructional Design Model for Undergraduate Chemistry Teaching Laboratory Design: Approach

The above-referenced protocol is considered exempt after review by the Institutional Review Board pursuant to Federal regulations, 45 CFR Part 46.101(b)(1)(2).

This part of the federal regulations requires that the information be recorded by investigators in such a manner that subjects cannot be identified, directly or through identifiers linked to the subjects. It is necessary that the information obtained not be such that if disclosed outside the research, it could reasonably place the subjects at risk of criminal or civil liability, or be damaging to the subjects' financial standing, employability, or reputation.

You should retain a copy of this letter for your records.

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