PART I. ANALYZING THE DISTRIBUTION OF GAS LAW QUESTIONS IN CHEMISTRY TEXTBOOKS

PART II. ^{35}Cl NQR SPECTRA OF GROUP 1 AND SILVER DICHLOROMETHANESULFONATES

by

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ABSTRACT

PART I: ANALYSIS OF THE DISTRIBUTION OF GAS LAW QUESTIONS IN CHEMISTRY TEXTBOOKS

PART II: ^{35}Cl NQR SPECTRA OF GROUP I AND SILVER DICHLOROMETHANESULFONATES

Part I. Two studies involving the gas law questions in eight high school and Advanced Placement/college chemistry textbooks were performed using loglinear analysis to look for associations among six variables. These variables included Bloom's Taxonomy (higher-order, lower-order), Book Type (high school, college), Question Format (multiple-choice, problem, short answer), Question Placement (in-chapter, end-of-chapter, test bank), Representation (macroscopic, particulate, symbolic), and Arkansas Science Standard (conceptual, mathematical; gas laws, pressure conversion, stoichiometry). The first study, involving the conceptual gas law questions, found the Book Type and Question Placement variables had the biggest impact, each appearing 5 of the 11 significant associations. The second study, involving the mathematical gas law questions, found the Question Placement had the biggest impact, appearing in 7 of the 11 significant associations, followed by Book Type and the Arkansas Science Standard variables, which appeared in 5 of the 11 significant associations. These studies showed that compared to the high school books, college books have fewer multiple-choice questions (compared to short-answer and problem questions), fewer in-chapter questions (compared to end-of-chapter and test bank questions), fewer questions in the chapters and

more questions at the end of the chapters, fewer multiple-choice questions in and at the end of the books, and more multiple-choice questions in the test banks.

Part II. The dichloromethanesulfonate salts of several +1 charged cations, $M^+Cl_2CHSO_3^-$ (M = Li, Na, K, Rb Ag, Cs Tl) were synthesized and studied by ^{35}Cl nuclear quadrupole resonance (NQR). Dichloromethanesulfonic acid was prepared by the methanolysis of dichloromethanesulfonyl chloride, which was neutralized with the metal carbonates to produce the corresponding metal dichloromethanesulfonate salts. This study completed the NQR investigation of the family of chloroacetates and chloromethanesulfonates of silver. The study suggests that the ability of organochlorine atoms to coordinate to silver ions deceases as the number of electron-withdrawing groups attached to carbon atom bound to the coordinating chlorine atom increases. The unusually large NQR spectral width found among $M^+Cl_2CHCO_2^-$ salts are not present among $M^+Cl_2CHSO_3^-$ salts and does not appear to be generally characteristic of the dichloromethyl family of salts.

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CHAPTER 1. INTRODUCTION

Introduction and Problem Statement

The main reason I decided to perform a textbook analysis as part of my dissertation is that as an educator with 20-plus years in the high school classroom, I am concerned with the style in which the content material is presented to students and how students' understanding of the material is being assessed. Early in my career, I observed that the questions appearing on tests, especially external test not written by the instructor (like the SAT, ACT, or the more recent No Child Left Behind assessments), were not of the same type as those presented in the textbook chapters. I also observed that sometimes the tests emphasized material that was a minor part of the chapter. Therefore, I chose to make my own tests that mirrored what was being taught in my classrooms. This way, I could control what concepts were tested (choosing the ones I thought were most important in the larger scheme) and how the students were being assessed.

Several science educators have noted that textbooks seem to control the content and the pace of the science courses. Textbooks are seen by students and parents, as well as teachers, to be the sole source of information to be covered in the chemistry class *(1-3)*. Students want a textbook that will give them every answer or detailed examples showing them every possible situation that they may encounter on their chemistry tests *(4-6)*. I have been through my share of textbook adoption cycles and have observed that textbook representatives place more emphasis on the auxiliaries (PowerPoint lessons, test banks and test generators, student workbooks etc.), rather than the textbook itself. The chemistry textbooks that appear on the Arkansas state book adoption list (and can be used in Arkansas high schools) were placed on this list because they cover the content material in the Arkansas chemistry frameworks *(7)*. Many Arkansas teachers choose one textbook over another because of the auxiliaries, the book representative, or prior experience with the textbook or textbook author. What the textbook itself actually brings to the classroom seems to be a minor detail in the decision-making process, since teachers focus on the auxiliaries that are intended for the teacher instead of focusing on the textbook that is intended for the student.

Unfortunately, textbooks are often the ultimate authority in high school chemistry classes, and teachers often defer to the written text even if they think it is incorrect. This is a problem because these textbooks often have mistakes in them. There have been numerous articles appearing in the *Journal of Chemical Education (JCE)*, the leading journal for high school chemistry teachers, dealing with specific textbook errors or misconceptions *(8-16)*. Although these textbooks are updated constantly, many of the errors are not corrected in the next addition of the textbook, even after these errors have been reported. Errors and misconceptions are not limited to chemistry textbooks, but appear in textbooks covering other areas (i.e. history, government, mathematics, etc).

Recognizing that textbooks not only dictate what chemistry concepts are taught, but also how they are taught, several articles appearing in *JCE* describe new or better methods of teaching chemistry concepts *(17-23)*, with the hope that textbooks authors (and instructors) will use these new methods. The instructor's teaching style is also dictated by the composition of the class. What works for one section might not work completely for another section. Also, what works for a same course one year or semester might not work completely for the course the next year or the next semester.

The only article in *JCE* that analyzed the types of questions used in chemistry textbooks was performed in 1935 *(24)*. This study analyzed the percentage of the textbook occupied by calculation questions. The author analyzed 12 high school chemistry textbooks according to four criteria: the number of problems in the book, the amount of space devoted to the problems, the types of problems, and the kind of mathematical operations needed to solve the problems. The author found a total of 1282 problems in the textbooks surveyed, taking up about one to two percent of the book. Reacting weights (stoichiometry), weight and density, gas laws, and composition accounted for 91 percent of the total book space devoted to problems. It was found that proportions could be used to solve 60 percent of the problems, while 14 percent used multiplication, 17 percent used division, 7 percent used addition, and 2 percent used subtraction. It would be interesting to see how the distribution of calculation questions in chemistry textbooks have progressed through the decades, but this study was never performed. Since the last study in *JCE* that analyzed the distribution of questions in chemistry textbooks was published in 1935, this area seemed ripe for study.

Independent Variables

In this study, I categorized the questions in the gas law chapters of eight books based on six variables. These variables were Bloom's Taxonomy (BL), Book Type (BT), Question Format (QF), Question Placement (QP), Representation (RP), and Arkansas science standard (ST). I chose the gas law chapters because they cover topics that are macroscopic, particulate, and symbolic (the three chemical representations), and because they contain questions that are mathematical (calculations) and conceptual (non-mathematical) in nature. In order to simplify the statistics (and the explanations of the statistical results), I separated the conceptual and mathematical questions and performed two different analysis studies. The study for the conceptual questions appears in Chapter 2 and the study for the mathematical questions appears in Chapter 3.

Bloom's Taxonomy. Benjamin Bloom identified are six levels of cognitive domain *(25)*—knowledge, comprehension, application, analysis, synthesis, and evaluation. The lowest level, knowledge, requires the student to exhibit memory of previously learned materials by recalling facts, terms, basic concepts, and answers. The next level is comprehension, in which the student demonstrates an understanding of facts and ideas by organizing, comparing, translating, interpreting, giving descriptions, and stating main ideas. The third level, application, requires the student to use new knowledge to solve problems by applying acquired knowledge, facts, techniques, and rules in a different way. The fourth level is analysis, in which the student examines and breaks information into parts by identifying motives or causes, makes inferences, and finds evidence to support generalization. The next level, synthesis, requires the student to compile information together in a different way by combining elements into a new pattern or proposing alternative solutions. The final level is evaluation, in which the student presents and defends opinions by making judgments about information, validity of ideas, and quality of work based on a set of criteria.

Science educators *(26-30)* often combine the first three levels (knowledge, comprehension, and application) together and refer to them as lower-order cognitive skills (LOCS) or lower-order thinking skills (LOTS). The top three levels of Bloom's

Taxonomy (analysis, synthesis, and evaluation) are referred as higher-order cognitive skills (HOCS) or higher-order thinking skills (HOTS). LOCS questions are those that require simple recall of information or a simple application of known theory or knowledge to familiar situations and context. HOCS questions combine these levels to represent problems unfamiliar to the student that require more than just the basic levels to come to a conclusion. HOCS can include the application of known theory or knowledge unfamiliar situations.

Zoeller, et al. *(26)* investigated the responses of students in three Israeli and American universities to algorithmic, lower-order cognitive skills, and conceptual (higher-order) chemistry exam questions. The study showed that students in all three universities performed consistently on questions in each of the three categories. Success on algorithmic questions did not imply success on conceptual or LOCS questions, and students taught in small classes outperformed those in larger lecture classes. The study showed that students who can perform successfully at the lower Bloom levels, which require memorization and technical skills, may do not have the conceptual understanding to perform successfully at the higher Bloom levels.

Domin *(27)* analyzed ten general chemistry laboratory manuals for evidence of HOCS activities. His study found that the majority of the laboratory tasks found in the laboratory manuals required the use of only the lower-order cognitive skills. Only two of the ten manuals utilized higher-order cognitive skills. The authors suggested that students should be allowed to design and develop their own experiments to investigate chemistry concepts in order to foster the higher-order cognitive skills. However, this method does present a problem in the management of laboratory time and resources. Students in the same laboratory sections may design different experiments to investigate the same concept and would invariably cause difficulties in making sure that all the needed chemical and equipment are available and in working order for the students to perform the experiment.

Pavelich *(28)* described methods that can be used in chemistry lecture to promote higher-order cognitive skills. In the chemistry lecture, an instructor can help students foster these skills by asking questions that must be answered after the student has analyzed the given information instead of asking rhetorical questions or questions involving remembering simple facts. This style of teaching can also be extended to the laboratory, in which students would be exposed to higher-order questions by the laboratory instructor.

The reason I included the Bloom's Taxonomy variable in this study is that high school chemistry textbooks tend to have mostly LOCS questions while college textbooks tend to have mostly HOCS questions. The reason high school textbooks have LOCS questions is because this is the generally the first time a student encounters chemistry and these types of questions help the student grasp the fundamental concepts of chemistry. A student, who is taking chemistry at the college level has probably had at least one year of chemistry, either at the high school level or a preparatory chemistry course and would not need the introductory LOCS questions. In addition, it has been my experience that multiple-choice questions generally use the LOCS level of questioning, while the short answer questions generally use on the HOCS level of questioning. Teachers should expect their students to be capable of answering both LOCS and HOCS questions. Although the Bloom's Taxonomy variable appears in the study of the mathematical questions, it was removed from the study of the conceptual questions because the initial loglinear tests that we performed using all six variables showed no significant associations involving this variable.

Book Type. The chemistry textbooks in this study were chosen from the list of books approved for high school/Advanced Placement chemistry courses issued by the Arkansas State Board of Education. The textbooks on this list were narrowed to four high school and four college textbooks based on my ability to find copies of the textbooks and the corresponding test banks. The four high school textbooks used this study were *Chemistry: Matter and Change (31, 32)*, *Chemistry: Concepts and Applications (33, 34)*, *Chemistry (35, 36)*, and *Modern Chemistry (37, 38)*. The four college chemistry textbooks used in this study were *Chemistry, 6th edition (39, 40)*, *Chemistry: The Central Science, 10th edition (41, 42)*, *Chemistry: Principles and Reactions, 4th edition (43, 44)*, and *Introductory Chemistry: A Foundation, 5th edition (45, 46)*.

The high school chemistry books are generally used for students who are taking chemistry for the first time and were written at a basic level to help guide the student through the nuances of chemistry. Even though Arkansas state frameworks expect the content from the entire book to be covered during the school year, about half of the material is generally covered. This is equivalent to the first semester of a college chemistry course. The difference is that the high school course covers the same material in twice the time, allowing high school students to study this material at a slower pace and in more detail.

The college chemistry books are generally used in Advanced Placement classes in high schools. These books are written for students who have studied chemistry for at least one year. An Advanced Placement course is the second chemistry course for most students, although there are some students who will take Advanced Placement chemistry without taking a first-year chemistry course. The first part of an Advanced Placement course is generally a review of the chemistry concepts that students learned during the previous school year. The rest of the school year is spent learning the concepts and style required to be successful on the Advanced Placement test, which is given at the end of the school year.

Because chemistry textbooks chosen for an Arkansas high school will be used for six years (the time frame of state book adoption cycle), the teacher must be careful when choosing a textbook. College instructors have more freedom in choosing a new textbook since the adoption cycle for college chemistry textbooks is about two years. The reason for this difference is that the school districts buy the high school textbooks, but the students buy the college textbooks. This difference is also reflected in the revision cycles for high school textbooks (which are revised every six years or so) and college textbooks (which are revised every two years or so).

From my prior experience as a student and a teacher, I found that generally high school textbooks generally have fewer questions than college textbooks. High school textbooks introduce the student to the concepts of chemistry. As more questions are added to the textbook, one of two things will happen. Either there are fewer pages devoted to explaining the concepts of chemistry or more pages are added to the textbook to compensate for the increase number of problems. One way that textbook authors have tried to limit the number of pages in their textbook is to have stand-alone workbooks with additional questions so that the student can practice. College textbooks usually do not have a separate student workbook, so there would be more questions in the book itself. I have also observed that high school textbooks generally have more LOCS questions than HOCS questions compared to college textbooks. I have also observed the test-bank questions generally tend to be of the multiple-choice format compared to the short-answer/problem format found in the textbook itself. The book drives what concepts will be taught in the chemistry course because the concepts that are to be taught in the chemistry course were taken from the book.

Question Format. Early in this study, we categorized the questions as multiple-choice, true-false, matching, short answer, or problem. While there were many questions using the multiple-choice, short answer, and problem format, there were very few using the true-false and matching formats (and those were predominately in the high school books). When performing chi-square tests (which are similar to the loglinear analysis I am using), if there are categories within a variable having very low frequencies, these categories are usually combined together or combined with other more populated categories within the variables. To decrease the number of low-frequency categories, I decided to combine the true-false and matching questions with the multiple-choice questions into one category—multiple-choice. This was an appropriate action since true-false and matching questions could be thought of as multiple-choice questions in that they all provide the students with a choice of possible answers from which to choose.

Multiple-choice format is frequency used for assessing student performance, not only on the examinations in the chemistry classroom, but also for national standardized tests. These tests include the America Chemical Society (ACS) national examinations (other national content examinations), and career/college placement examinations like the Scholastic Assessment Test (SAT), the American College Test (ACT), the Armed Services Vocational Aptitude Battery (ASVAB), and others. The No Child Left Behind assessments (handled by the National Assessment of Educational Progress) that must be administered every two years, and which have implications for state and local school districts, also include multiple-choice questions. Advance Placement tests also include multiple-choice questions. One reason why these national tests use the multiple-choice format is that it is quicker and more objective to grade than other formats. Although other national examinations (most notably the Advanced Placement examinations) also use other formats, they take longer to grade and require experts to analyze students' responses. Holme *(42)*, the current director of the ACS Exams Institute, noted that writing good multiple-choice questions are "challenging" because they must be written well enough that there is a clear and concise understanding of what concepts the student must understand to answer the question. Also, the answers must have logical and well-designed distractors so that the mistakes and misconceptions commonly exhibited by students are represented in the multiple-choice questions.

The short-answer format requires the student to provide an answer, typically in two to three sentences or less. Short-answer questions can be easy to write, but are harder to grade. While multiple-choice questions ask students to pick the best answer from a list of teacher-provided choices, short-answer questions require the student to supply the answer. The disadvantage of short-answer questions is that it is more difficult to grade them objectively. Teachers often create a rubric to make the grading process more consistent and objective. Although the multiple-choice format appeared in the analysis of both the conceptual and mathematical questions, the short-answer format only appeared in the analysis of the conceptual questions (students are not asked to provide a short answer regarding how they solved a mathematical question; instead, they are usually asked to show the calculations).

The problem format requires the student to perform a mathematical calculation that results in a numerical answer. This explains why this format appeared in the analysis of the mathematical questions but not in the analysis of the conceptual (non-mathematical) questions. Often problem questions can be solved using a mathematical algorithm, including dimensional analysis *(48-54)*. Dimensional analysis, also called the factor-label method, is a process in which the student uses the units of the individual numbers supplied in the question to determine how these values will be mathematically manipulated (multiplied, divided, added, etc.). Several chemical educators have advocated the use of dimensional analysis *(48-50)*, but others have argued against the use of dimensional analysis *(51-54)*.

According to Drake *(49)* the advantage of dimensional analysis is that the student can use this method to solve a problem without reverting back to an equation. In his method, the student must first determine what the units for the answer will be and then work are "backward" to add the desired units and eliminate the units not desired in the answer. Beichl *(50)* notes that dimensional analysis can enable the student to determine which experimental data are needed to solve the problem and will help students resists the temptation of trying to use all the information found in the problem whether it is needed or not. His conclusion is that once this process is mastered, dimensional analysis provides a logical support system for student venturing into problem solving that requires an understanding of the mathematical processes as well as the underlying chemistry concepts.

Cook *(51)* argues that dimensional analysis, even though it is a powerful and efficient method of solving problems, allows the student to solve a problem by following a “mindless” process rather than understanding why and how the units are being cancelled due to scientific principles. The author suggests that cross-proportion (ratio-and-proportion), which requires the student to understand the underlying chemical principles in order to set up the correct proportion to solve the problem, is a better method.

This debate has continued for the past two decades and both arguments are valid in that each allows the student to solve the problem. I believe that both methods can be taught to the chemistry student, depending on the level of the student’s mathematical ability of the student. The cross-proportion method could be taught first because it is a method that the student has learned in their math classes. The instructor can then introduce dimensional analysis in the same section or introduce it in a later section of the course.

The ease at which a question is developed depends on the question format. A short-answer or a problem question can be written quickly (in a minute or so). The developer can write many of these questions in a given time period compared to the time it takes to develop one good multiple-choice question. Given the time constraints that normally occur when some textbooks and test banks are revised and published, it is no wonder that there are more short-answer and problem questions in the textbooks. The reason why there are more short-answer and problem questions in the textbooks than in the test banks is that the questions are usually given as in-class examples to be worked out or as homework to be gone over the next class period. One reason for the predominance of multiple-choice questions in the test banks could be that the students expect to receive their graded tests in the next class period. Therefore, the instructor has little "turn-around" time to grade the exams and may favor multiple-choice questions.

I expect that short-answer questions would appear more often in high school textbooks compared to college textbooks, while problems would appear more often in college textbook compared to high school textbooks. Short-answer questions are used to introduce the student to chemistry concepts and this is the goal of the high school or the first-year chemistry course. In a college chemistry course, the problem questions often require the student to apply the concepts of the short-answer questions that the student learned in the previous course. Most problem questions involve some sort of mathematical process in addition to reading and analyzing the information in the question. Therefore, problem questions would tend to be HOCS questions.

Question Placement. The questions in a textbook typically appear within the chapter itself, at the end of the chapter, or in the test bank. The in-chapter questions are primarily used to introduce concepts to students and to show them how to perform calculations. These questions can also be used by students to assess whether they understand the newly introduced concepts, and by the teacher as a way to monitor the learning process of the students. These questions are unique in that they not only show the question, but also provide the answer and an explanation of how to answer the question or perform the calculation.

The end-of-chapter questions are generally used to assess student performance before they take an examination over this material (formative assessment). This assessment can be done by the teacher if the student is required to turn in a homework assignment and the teacher grades this assignment and provides constructive feedback. The major disadvantage of assigning, collecting, and grading homework is that this takes a large time commitment from the teacher to grade these assignments and provide feedback for incorrect answers. It is also possible that some students will not look at the assigned problems until the day it is due and will complete the assignment when they come to the teacher for "extra help" at the last minute or simply decide to copy the answers from another student who has spent the time at home completing the assignment. If the homework is not turned in, the student can still assess his or her own learning if the answers for the questions appear at the end of the textbook or in a solutions manual. The disadvantage of this method (which is very popular in college chemistry courses) is that there is no guarantee the student will even look at the assignment or try to answer the homework questions.

The test-bank questions are primarily used by teachers to create examinations for their students (summative evaluation). The advantage of using test-bank questions is primarily a matter of saving time for the instructor. Instead of creating their own questions, the instructor looks through the test-bank questions, choosing questions that are appropriate or relevant to the material discussed in their classes. The disadvantage is that there may not be any questions in the test bank that perfectly match the instruction of the classes, and the instructor may be forced to choose questions that are less relevant or appropriate as part of his or her examination. Although some test banks are written by the textbook authors, many are written by other authors and it is possible that the questions in the test bank may not match the content or emphasis of the textbook. There are usually more questions in the test bank that can be completed by the student in a normal class period of 50 minutes. The teacher will have to choose the number and type of questions that the students will answer for the test. The teacher can retype the questions from the test-bank book or can use a test generator to develop the test. Instructors who are not fully comfortable with the chemistry content discussed in their classes (e.g., biology teachers who have been asked to teach chemistry) may be more likely to rely on the test bank for their assessment activities than teachers who are more comfortable with the content.

I have observed that most of the questions in high school textbooks are located at the end of the chapter. This is also true for college chemistry textbooks. I have also observed that there are more in-chapter questions in high school chemistry textbooks compared to college textbooks. The reason for this is that high school chemistry students need frequent reinforcement and “check points” of the concepts and the in-chapter questions provide this. College chemistry textbooks do not have many in-chapter questions because the textbook authors are assuming that the student who is taking the course has a basic knowledge of chemistry and does not need as much reinforcement. As I have mentioned before, multiple-choice questions are predominantly found in the test bank. Also, in-chapter questions tend to be LOCS-type questions because these questions are used to make sure that the students is grasping the chapter concepts. End-of-chapter questions tend to have a more even distribution of LOCS questions and HOCS questions because the student should have a good grasp of the concept being studied in that chapter when doing the homework problems.

Representation. The questions were categorized according to the representations of matter *(55-57)*—macroscopic, particulate (microscopic), or symbolic. The macroscopic representation includes data and observations involving one or more of the human senses. Examples include color changes, precipitation (solid formation), bubbles (gas formation), odors, etc. They also include data collected in the laboratory like masses, volumes, temperatures, etc. The particulate (also called microscopic or sub-microscopic) representation involves the interactions of atoms, molecules, and ions. The particulate representation is very important in chemistry and is what makes this field unique from other branches of science. The symbolic representation involves the use of symbols to stand for other objects. The most common symbols used in chemistry are the chemical symbols from the periodic table (e.g., H standing for hydrogen, O standing for oxygen, etc.). Chemical formulas (like H_2O for water or NaCl for salt) and balanced chemical equations (like $H_2 + O_2 \rightarrow 2\ H_2O$) are also symbolic representations that make use of the chemical symbols described above as well as other symbols (the subscripted number, the numbers in front of the chemical, the plus signs, the arrow, etc.). Mathematical formulas (like $PV = nRT$), calculations, and graphs are another place where chemists use the symbolic representation.

Students usually experience the macroscopic representation in the lecture in the form of chemical demonstrations and in the laboratory in the form of chemical experiments. Students tend to have little trouble with macroscopic questions because they can directly observe the process. As long as the student records what they actually observed, rather than what they think the teacher wants them to observe, the student will be poised to learn the chemical concepts being taught in the course. Traditional chemistry classes tend to introduce the concept in the lecture, and then watch demonstrations or perform experiments to collect macroscopic data that will confirm what the students were already taught. Inquiry-based lessons, on the other hand, often start with the macroscopic observations (demonstrations or experiments) and then use these common experiences to construct the concepts to be taught in the course.

Students experience the symbolic representation in a number of ways in the chemistry classroom. Students are taught early to recognize the chemical symbols of the most-commonly used elements, and also learn to balance chemical equations early in their chemistry courses. They are also taught early in their chemistry classes to perform mathematical calculations in the lecture and the laboratory. Traditional chemistry classes tend to focus on the symbolic representation and it represents a powerful tool. Students who are not comfortable with abstract ideas (like the use of symbols to stand for other things, analogical thinking, or proportional reasoning) tend to have more difficulty in chemistry classes *(58, 59)*.

Many students do not receive detailed instruction involving the particulate representation. This is not because the instructor does not view this as an important topic to discuss, but because the student cannot readily observe the processes that are proceeding on the particulate level *(60)*. Computer animations are one way a teacher can help the student visualize particulate behaviors. Several chemical educations researchers have published articles in *JCE (60-64)* testing the effectiveness of using computer animations to help the student answer particulate questions. Kelly and Jones *(61)* noted that animations help the student visualize particulate processes and develop good chemical understanding. The animations showed believable representations and, therefore, students constructed their new knowledge that was consistent with scientifically-accepted explanation. Yezierksi and Birk *(62)* used animations for organic mechanisms. An animation with modeled reaction mechanisms was shown to be a better means of visualizing organic reactions rather than the two-dimensional method using paper and pencil or using a chalkboard. Sanger, Phelps, and Fienhold *(63)* noted that animations help the student to be better prepared to answer questions about particulate phenomena. Burke, Greenbowe, and Windhschitl *(64)* noted that animations increased student's understanding and performance on conceptual exam questions. Sanger *(60)* summarized the chemical education research involving the use of computer animations and described the theoretical frameworks explaining why computer animations should help students learn concepts at the particulate level.

Since macroscopic questions and in-chapter questions are both used to introduce concepts to the students, the macroscopic questions should be the most common in-chapter question. Some particulate questions would probably be found in the in-chapter questions after the concept has been introduced but should have more questions in the end-of-chapter section of the textbook. High school chemistry textbooks should have more macroscopic-level questions compared college chemistry textbooks. College chemistry textbooks should have more particulate questions compared to high school textbooks because the textbook authors have assumed that the student is comfortable with the macroscopic concepts.

Most macroscopic and some symbolic questions would be classified as LOCS questions because students would be familiar with the prior observations and mathematical skills. Particulate questions should be mostly HOCS questions because they require the student to use more than one piece of information or concept to answer them. I would expect that the in-chapter questions would be mostly LOCS with the end-of-chapter and test-bank questions evenly divided between LOCS and HOCS type questions. The symbolic calculation questions could be classified as LOCS or HOCS, depending on how many steps does it take to solve the problem. Although the Representation appears in the study of the conceptual questions, it was removed from the study of the mathematical questions because all mathematical calculations, by their very nature, are symbolic questions. So, there were no macroscopic or particulate questions being evaluated in the study involving the mathematical questions.

Arkansas Science Standard. The Arkansas Science Framework Standards *(7)* were revised in 2005 and have three standards addressing the properties of gases. These standards appear in Table 1.

Standard 16 (GL.16.C.1) relates to a student's particulate-level understanding of the behavior of gas particles using the kinetic-molecular theory (KMT). Standard 17 (GL.17.C.1) relates to a student's understanding of the mathematical relationships between temperature, pressure, volume, and moles of a gas using the gas law equations. This includes several topics normally covered in chemistry textbooks, including the individual gas laws (Avogadro's law, Boyle's law, Charles' law, and Gay-Lussac's law), the ideal gas law, the combined gas law, partial pressures, and effusion. Standard 16 (GL.16.C.2) and Standard 18 (GL.18.C.1) relate to a student's understanding of the

Standard 16: Student shall understand the behavior of gas particles as it relates to the kinetic theory.

GL.16.C.1	Demonstrate the relationship of the *kinetic theory* as it applies to *gas* particles: • *molecular motion* • *elastic collisions* • *temperature* • pressure • ideal gas
GL.16.C.2	Calculate the effects of *pressure, temperature,* and volume on the number of *moles* of *gas* particles in *chemical reactions*

Standard 17: Students shall understand the relationships between *temperature, pressure,* volume, and *moles* of a *gas.*

GL.17.C.1	Calculate the effects of *pressure, temperature,* and volume to *gases*

Gas Law	Formula
Avogadro's Law	$V_2 = V_1 \frac{n_2}{n_1}$
Boyle's Law	$P_1V_1 = P_2V_2$
Charles' Law	$\frac{V_1}{T_1} = \frac{V_2}{T_2}$
Combined Law	$\frac{P_1V_1}{T_2} = \frac{P_2V_2}{T_1}$
Dalton's Law of Partial Pressure	$P_{Total} = P_1 + P_2 + P_3 \ldots$
Graham's Law of Effusion	$\frac{v_1}{v_2} = \sqrt{\frac{m_2}{m_1}}$
Guy-Lussac	$\frac{P_1}{T_1} = \frac{P_2}{T_2}$
Ideal Gas Law	$PV = nRT$

Standard 18: Student shall apply the *stoichiometric mass* and volume relationships of *gases* in *chemical reactions.*

GL.18.C.1	Calculate volume/*mass* relationships in balanced *chemical reaction equations*

Table 1. Arkansas Science Framework Standards—Gas Laws

mathematical relationship between stoichiometric mass and the properties of a gas (volume, pressure, temperature, and moles) using chemical reactions.

It is not clear why Gas Law Strand 16.C.2 was combined with Gas Law Strand 16.C.1 instead of Gas Law Strand 18.C.1. In my analysis of the conceptual questions using the Arkansas Science Framework Standards, I used Gas Law Strand 16.C.1 as the kinetic-molecular theory standard, Gas Law Strand 17.C.1 as the gas law standard, and I combined Gas Law Strands 16.C.2 and 18.C.1 together as the stoichiometry standard. In my analysis of the mathematical questions, there were no questions that were categorized as being kinetic-molecular theory standard (16.C.1), so this standard was dropped from this analysis. The gas law (17.C.1) and the stoichiometry (16.C.2 and 18.C.1) standards were well-populated and were kept for this analysis. There was another topic appearing in the mathematical questions of the eight textbooks that does not appear in the Arkansas Science Framework Standards—the conversion of pressure values from one unit to another. This new topic was added as the third category in the Standard variable for the analysis of the mathematical questions.

I would expect a majority of the questions to be those concerning the gas law standard with the kinetic-molecular and the stoichiometry standards evenly distributed among the remaining questions. The mathematical calculations involving the gas law equations are generally perceived to be the most important part of the gas law chapters, therefore the majority of the end-of-chapter and test-bank questions should involve this standard. The gas law equations would be mostly LOCS questions because the student will be asked to substitute numbers into a specific equation. The KMT and stoichiometry should be predominantly HOCS because KMT questions involve particular situations and stoichiometry would involve more than one mathematical step in order to solve the problem. I believe that the KMT questions will be predominantly particulate-level questions, while the gas law and stoichiometry questions will be symbolic-level (calculations) questions.

Data Analysis

I categorized each question in the eight chemistry textbooks and their test-banks according to all six variables. For questions with multiple parts, each part was analyzed as a separate question. There were 2,313 questions analyzed—740 of these were conceptual questions (the first study) and 1,573 were mathematical questions (the second study). In order to determine the reliability of my categorization scheme, my major advisor categorized the end-of-chapter questions for *Chemistry: The Central Science (41)* and our results were compared. The inter-rater reliability of the categorization scheme was 0.86. The discrepancies in the question categorization may have been due to my inexperience or the vague wording of some of the questions. Cassels and Johnstone wrote that language does have an effect on the way a student answers the questions *(65)*. After discussing all discrepancies, we agreed how to categorize the vague questions identified after the first reliability comparison. After fine-tuning our categorization scheme, my major advisor analyzed the in-chapter questions in *Modern Chemistry (37)*; our revised categorization scheme had an inter-rater reliability of 0.96, which we agreed was acceptable.

The frequencies (numbers) of questions with the same values for all six independent variables were tallied. The dependent variable in this study is the frequency of questions appearing in each mutually-exclusive category (cell). These nonparametric frequency data were analyzed using Loglinear Analysis *(66)*, which is an extension of the statistical method of Multiway Frequency Analysis *(67)*.

We used the LOGLIN function of the statistical program SYSTAT to perform the loglinear analyses in this study *(68)*. Each loglinear analysis was performed using a saturated model, in which all one-, two-, three-, and higher-way associations were tested. When a saturated model is used, the highest-order association is tested first. Then, the next highest-order associations were tested with the effect of the highest-order association removed ("partialed out"). The process continues from highest- to lowest-order associations with the effects of all higher-order associations removed before a test is performed. Because of this partialing effect, the results of a two-way association test between variables may be very different than the chi-square test of independence performed between these two variables because the chi-square test does not correct for higher-order associations.

According to Tabachnick and Fidell *(66)*, multiway frequency analyses make no assumption about population distributions and are remarkably free of limitations. These authors describe four practical issues affecting the power of loglinear results. The first issue is that all the categories are required to be mutually exclusive, so that each categorized question falls into only one cell. This requirement was met for all four analyses in these studies. The second issue is there should be at least five times as many cases (questions) as cells in this study. In the first study, there were an average of 20.55 questions per cell; in the second study, there were an average of 43.69 questions per cell. The third issue is that when cases are rare (less than five), the marginal frequencies may not be evenly distributed. They suggest that the expected cell frequencies for all the two-way associations should be examined to assure that all are greater than one, and no more than 20% are less than five. Two of the four analyses did not meet this requirement because then had one or two cells (out of 37) with a frequency of zero. The only way to address the loss of power due to zero-frequency cells would be to increase the sample size by analyzing more textbooks. However, it is unlikely that analyzing more textbooks will eliminate these zero entries. Therefore, we have decided to accept the loss of power associated with having a zero entry in these cells. The fourth issue is that when performing non-saturated analyses, there may be substantial differences between observed and expected frequencies that make it impossible of the data to be adequately fit by the proposed model. Since we performed saturated tests, this is not an issue.

My research question for the four analyses was "Are there any significant associations among the variables in this analysis?" Non-significant associations mean that the distribution of questions among these variables is homogeneous. If the questions tend to cluster together in a few cells, then the questions are not homogeneously distributed and the association among these variables would be significant.

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CHAPTER 2. ANALYZING THE DISTRIBUTION OF GAS LAW QUESTIONS IN CHEMISTRY TEXTBOOKS—CONCEPTUAL QUESTIONS

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Abstract

The conceptual questions from the gas law chapters of eight high school and college chemistry textbooks were analyzed to look for associations among five variables—Book Type (high school, college), Question Format (multiple-choice, short answer), Question Placement (in-chapter, end-of-chapter, test-bank), Representation (macroscopic, particulate, symbolic), and Arkansas Science Framework Standards (conceptual, mathematical). Book Type and Question Placement appeared to have the biggest impact, appearing in seven of the eleven significant associations. This paper discusses possible reasons why the distribution of questions would be different for high school and college textbooks and why it would be different for in-chapter, end-of-chapter, and test-bank questions. Most test-bank answers appeared in multiple-choice

format but few in-chapter or end-of-chapter questions used multiple-choice. Given that many national standardized tests use multiple-choice, textbook authors and chemistry instructors need to provide multiple-choice questions for students to practice, either at the end of the chapters or in supplemental homework assignments.

Introduction

For many high school and college chemistry instructors, the textbook dictates what chemical concepts are taught in the classroom and in what order they are taught. Teachers often view the textbook as, and students expect it to be, the sole source of information and as dictating the content to be covered *(1-3)*, and parents complain if science textbooks were not issued and used as the basis of school assignments *(3)*. Published textbooks are used in 90% of secondary science courses and 75% or more of the content is covered in class *(4)*, textbooks have become encyclopedias of science facts that encourage teachers and students to focus on memorization *(5-7)*, and the current way textbooks are used can lead to student misconceptions *(8-10)*. With the advent of No Child Left Behind (NCLB), textbooks also play an enhanced role in the issues of assessment (*11-13*).

The topic of textbooks has been very popular in this *Journal*, appearing in articles from every decade since the *Journal's* inception *(14-30)*. While the earliest articles focused on educational issues associated with picking textbooks *(14-16)*, most recent articles have focused on either specific textbook errors and the possible misconceptions that could arise from these errors *(8, 19-21, 23, 25-27, 30)* or on new and better ways of teaching specific content material *(9, 17, 18, 22, 24, 28, 29)*. Only one article from 1935

(15) analyzed the problems that appear in chemistry textbooks; this paper focused on the percentage of the entire book occupied by calculation questions and the types of mathematical skills needed to solve these problems.

As a high school teacher who teaches Advanced Placement (AP) Physics B and introductory chemistry at a local community college in Arkansas, the first author was interested in evaluating how high-school and college chemistry textbooks helped students meet the Arkansas Science Framework Standards and helped them prepare for the one-shot end-of-year NCLB test. Since NCLB focuses on students' performance and has provisions to hold schools, districts, and states accountable for their students' performance, we decided to focus our textbook analysis on the assessment questions used in these textbooks.

Analyzing all of the questions in an entire textbook is a daunting task, so we decided to focus our analysis on the gas law chapters of four high school and four college (AP) books. We chose the gas law chapters because they contain a variety of questions based on different factors: calculations and conceptual questions; multiple-choice and short answer format *(31, 32)*; macroscopic and particulate and symbolic levels *(33, 34)*; and questions placed in the chapters, at the end of the chapters, and in the test banks. We also linked these questions to the three gas law standards in the Arkansas Science Framework Standards *(35)*. In this paper, we focused on the conceptual (non-calculation) questions within these textbooks; we are working on a second paper *(36)* that will focus on the mathematical (calculation) questions in these books.

We analyzed each conceptual question based on the five parameters described above. The research question for this study was: Are there any significant associations among the five variables in this study? The significant associations were then analyzed to explain any possible differences.

Methods

Data Collection. The in-chapter, end-of-chapter, and test-bank questions of the gas law chapters of four high school and four Advanced Placement/college chemistry textbooks were reviewed and analyzed. The high school textbooks and the correlating test banks used in this study were *Chemistry: Matter and Change (37, 38)*, *Chemistry: Concepts and Applications (39, 40)*, *Chemistry (41, 42)*, and *Modern Chemistry (43, 44)*. The college chemistry textbooks and test-banks used were *Chemistry, 6th edition, (45, 46)*, *Chemistry: The Central Science, 10th edition, (47, 48)*, *Chemistry: Principles and Reactions, 4th edition, (49, 50)*, and *Introductory Chemistry: A Foundation, 5th edition, (51, 52)*. These eight books were chosen because they were approved for use in high school/Advanced Placement chemistry courses by the Arkansas State Board of Education.

In addition to the categories of Book Type (BT) and Question Placement (QP) described above, each question (or each part for questions with multiple parts) in the textbooks/test-banks was categorized according to the following three specific criteria: Question Format (QF), Representation (RP), and Standards (ST) from the Arkansas Science Framework Standards.

The Question Format category originally included multiple-choice, true-false, matching, and short answer. We decided to collapse the multiple-choice, true-false, and matching questions into one category (multiple-choice) since they all represent questions where students were given a choice of answers. A short-answer question required students to provide an answer on their own.

The questions were also categorized by their Representation *(33, 34)*—macroscopic, particulate (microscopic), or symbolic. Macroscopic questions deal with observable concepts involving one or more of the human senses to answer the questions. Particulate questions deal with answers at the atomic or molecular level. Symbolic questions were those that could be answered using symbols, numbers, mathematical concepts, or algorithms.

The Arkansas Science Frameworks Standards *(35)* were revised in 2005 and have three standards addressing the properties of gases. Standard 16A relates to a student's understanding of the behavior of gas particles using the kinetic-molecular theory (KMT). Standard 17 relates to a student's understanding of the mathematical relationships between temperature, pressure, volume, and moles of a gas. Standards 16B and 18 relate to a student's understanding of the mathematical relationship between the stoichiometric mass and the properties of a gas (volume, pressure, temperature, and moles) using chemical reactions. For the purposes of this paper, the standards were collapsed into two categories—conceptual (Standard 16A) and mathematical (Standards 16B, 17, and 18) *(53, 54)*.

Each question from the gas law chapters of eight chemistry textbooks and test banks were categorized by the first author. In order to determine the reliability of the categorization scheme, the second author categorized the end-of-chapter questions for *Chemistry: The Central Science (47)* and the results from the two authors were compared. The inter-rater reliability was 0.86. The discrepancies may have been due to the inexperience of the first author or the vague wording of some of the questions. Cassels and Johnstone argue that language does have an effect on the way students answer a question *(55)*. The authors discussed all discrepancies and agreed how to categorize the vague questions identified after the first reliability comparison. After the categorization scheme had been fine-tuned, a set of questions from another textbook were compared. The comparison of the in-chapter questions in *Modern Chemistry (43)* had an inter-rater reliability of 0.96.

Data Analysis. In this study, each part of every question ($N = 740$) was categorized according to the five categories. Then the frequencies (numbers) of questions with the same values for all five independent variables were tallied. These nonparametric frequency data were analyzed using Loglinear Analysis *(56)*, which is an extension of the statistical method of Multiway Frequency Analysis *(57)*. We used the LOGIN function of the statistical program SYSTAT to perform the loglinear analyses in this study *(58)*. Each loglinear analysis was performed using a saturated model, in which all one-, two-, three-, and four-way associations were tested. Significant associations occur when the computer determines that the frequency data are not homogeneously distributed among the individual cells.

According to Tabachnick and Fidell *(56)*, multiway frequency analyses make no assumptions about population distributions and are remarkably free of limitations. However, they caution about having too many variables since it can be very difficult to explain (or understand) three-, four-, or higher-order associations. For this reason, we decided to separate the conceptual and mathematical questions into two different studies. For the conceptual questions in this study, we also decided to perform two loglinear analyses of the data involving only four variables. In the first analysis, we collapsed the Question Format variable because it caused many cells with zero frequencies. The frequency table and the results for this loglinear analysis appear in Tables 1 and 2, respectively.

Book Type	Question Placement	Standard	Representation		
			macroscopic	particulate	symbolic
college	in-chapter	conceptual	1	8	0
		mathematical	8	0	0
	end-of-chapter	conceptual	48	86	14
		mathematical	16	0	19
	test-bank	conceptual	24	43	1
		mathematical	24	0	12
high school	in-chapter	conceptual	10	23	0
		mathematical	14	1	34
	end-of-chapter	conceptual	14	33	1
		mathematical	26	0	22
	test-bank	conceptual	27	53	11
		mathematical	61	1	105

Table 1. Observed Frequency Data for the Loglinear Comparison with Question Format Collapsed.

Source	*df*	χ^2 value	*p* value
Book Type (BT)	1	6.54	0.01[a]
Question Placement (QP)	2	21.16	0.00[a]
Representation (RP)	2	31.03	0.00[a]
Standard (ST)	1	4.25	0.04[a]
BT × QP	2	9.08	0.01[a]
BT × RP	2	1.39	0.50
BT × ST	1	4.86	0.03[a]
QP × RP	4	3.43	0.49
QP × ST	2	4.25	0.12
RP × ST	2	169.06	0.00[a]
BT × QP × RP	4	13.53	0.01[a]
BT × QP × ST	2	1.11	0.58
BT × RP × ST	2	3.22	0.20
QP × RP × ST	4	0.56	0.97
BT × QP × RP × ST	4	5.20	0.27

[a] $p<0.05$ corresponds to a significant association between these variables

Table 2. Loglinear Analysis Output for the Associations between the Independent Variables with Question Format Collapsed.

In the second analysis, we collapsed the Standard variable because in the complete five-way test (not described in this study), it showed the fewest associations with the Question Format variable. This was important because in performing the two smaller tests instead of the one bigger test, we lost the ability to test for any associations involving both Question Format and Standard. The frequency table and the results for the second loglinear analysis appear in Tables 3 and 4, respectively.

Book	Question	Question	Representation		
Type	Placement	Format	macroscopic	particulate	symbolic
college	in-chapter	multiple-choice	0	0	0
		short-answer	9	8	0
	end-of-chapter	multiple-choice	0	0	0
		short-answer	64	86	33
	test-bank	multiple-choice	48	43	13
		short-answer	0	0	0
high	in-chapter	multiple-choice	0	0	0
school		short-answer	24	24	34
	end-of-chapter	multiple-choice	0	0	5
		short-answer	40	33	18
	test-bank	multiple-choice	72	37	88
		short-answer	16	17	28

Table 3. Observed Frequency Data for the Loglinear Comparison with Standard Collapsed.

Source	*df*	χ^2 value	*p* value
Book Type (BT)	1	11.14	0.00[a]
Question Format (QF)	1	17.66	0.00[a]
Question Placement (QP)	2	16.10	0.00[a]
Representation (RP)	2	0.24	0.89
BT × QF	1	3.63	0.06
BT × QP	2	9.15	0.01[a]
BT × RP	2	4.10	0.13
QF × QP	2	427.56	0.00[a]
QF × RP	2	1.68	0.43
QP × RP	4	1.07	0.90
BT × QF × QP	2	8.92	0.03[a]
BT × QF × RP	2	0.01	1.00
BT × QP × RP	4	0.11	1.00
QF × QP × RP	4	2.88	0.58
BT × QF × QP × RP	4	2.59	0.63

[a]$p<0.05$ corresponds to a significant association between these variables.

Table 4. Loglinear Analysis Output for the Associations between the Independent Variables with Standard Collapsed.

Tabachnick and Fidell *(56)* also describe four practical issues affecting the power of loglinear results. The first issue is that all the categories must be mutually exclusive. This requirement has been met in this study. The second issue is there should be at least five times as many cases (questions) as cells; in both loglinear analyses in this study, there are an average of 20.55 questions per cell. The third issue is that when cases are rare (less than five), the marginal frequencies may not be evenly distributed. The expected cell frequencies for all two-way associations should be greater than zero, and no more than 20% should be less than five. In the analysis with the Question Format variable collapsed, there was only one cell out of 37 (3%) that was rare and none were zero. In the analysis with the Standard variable collapsed, there were no rare cells, but one cell out of 37 (3%) was zero—there were no questions that were categorized as in-chapter (Question Placement) and multiple-choice (Question Format). The only way to address the loss of power due to a zero entry would be to increase the sample size by analyzing more textbooks *(58)*. However, it is unlikely that analyzing more textbooks will eliminate this zero entry since very few textbooks use multiple-choice questions within the text. Therefore, we have decided to accept the loss of power associated with having a zero entry in one of the 37 cells. The fourth issue is that when performing non-standard analyses, there may be substantial differences between observed and expected frequencies that make it impossible for the data to be adequately fit by the proposed model. This is not an issue when performing saturated tests.

Results and Discussion

The results of the loglinear analysis with the Question Format variable collapsed showed four significant one-way associations (BT, QP, RP, and ST), three significant two-way associations (BT × QP, BT × ST, and RP × ST), and one significant three-way association (BT × QP × RP). For the loglinear analysis with the Standard variable collapsed, there were three significant one-way associations (BT, QF, and QP), two significant two-way associations (BT × QP and QF × QP), and one significant three-way association (BT × QF × QP). The four-way associations were not significant for either test.

For each association test, SYSTAT calculates standard normal deviate scores for each cell within the test. These values represent *z* scores that can be used to determine the influence of each cell on an overall effect *(56)*. A standard deviate score above +1.96 means that the observed frequency of a cell is significantly higher than would be expected if the questions were homogeneously distributed, and a standard deviate score below –1.96 means that the observed frequency of a cell is significantly lower than would be expected if the questions were homogeneously distributed (at the 0.05 level).

One-Way Associations. The test for one-way associations in a loglinear analysis is analogous to a chi-square goodness-of-fit test, which tests whether the cells within each variable have equal frequencies. Five of the variables (BT, QF, QP, RP, and ST) showed significant one-way associations; two of these associations (BT and QP) were significant in both tests.

<u>Book Type</u>. The four college chemistry textbooks had a total of 304 questions (an average of 76 questions per book) and the four high school chemistry textbooks had a

total of 436 questions (an average of 109 questions per book). In both tests, the standard deviate scores showed the number of questions in the high school textbooks was higher than expected and the number of questions in the college chemistry textbooks was lower than expected. Because high school chemistry courses are usually composed of students who are taking chemistry for the first time, while college chemistry courses typically contains students who have had a year of high school chemistry and are familiar with the concepts, it makes sense that college chemistry textbooks would have fewer questions than high school textbooks. Also, college textbooks usually will cover more concepts than high school textbooks and less space is allotted for questions.

Question Format. There were a total of 306 multiple-choice questions (41% of the total) and 436 short-answer questions (59% of the total). The standard deviate scores showed the number of short-answer questions was higher than expected and the number of multiple-choice questions was lower than expected. There are several reasons why textbook authors might write more short-answer questions than multiple-choice questions. First of all, short-answer questions are quicker to write. When writing multiple-choice questions, the author must put some thought into writing good distractors, and this can take some time. Second, coming up with good distractors, especially for conceptual questions, is difficult. So, it is not surprising that when writing conceptual questions, textbook authors write more short-answer questions than multiple-choice questions.

Question Placement. There were 99 questions (13% of the total) found within the textbook chapters, 279 questions (38% of the total) found at the end of the textbook chapters, and 362 (49% of the total) found in the test banks. When the Question Format variable was collapsed, the standard deviate scores showed the number of end-of-chapter questions and test-bank questions was higher than expected and the number of in-chapter questions was lower than expected. When the Standard variable was collapsed, the number of in-chapter questions was lower than expected and the number of test-bank questions was higher than expected. Because in-chapter questions show not only the question, but also detailed answers to the questions, they tend to take up a lot of space per question and each textbook contains very few of these questions. End-of-chapter and test-bank questions, on the other hand, do not take up as much space. So, having more of these questions allows students to have more homework examples to practice and more instructor choices for assigning grades (from homework or tests) without adding lots of extra pages to the textbooks.

Representation. There were a total of 273 macroscopic-level questions (37% of the total), 248 particulate-level questions (33% of the total) and 219 symbolic-level questions (30% of the total). The standard deviate scores showed the number of macroscopic level questions was higher than expected and the number of particulate-level questions was lower than expected. While these values were significantly different, the percentages of the macroscopic particulate, and symbolic conceptual questions were actually very similar. The reason we chose to analyze questions in the gas law chapters is that the content in these chapters focuses on all three representations—macroscopic (changes in pressure, volume, or temperature), particulate (explanations using kinetic-molecular theory), and symbolic (calculations involving pressure conversions, gas laws, and stoichiometry). The distribution of questions among the three representations may have been very different had we chosen a different chapter to analyze (e.g., stoichiometry or thermodynamics).

Standard. There were a total of 397 conceptual questions based on the conceptual standards (54% of the total) and 343 conceptual questions based on the mathematical standards (46% of the total). The standard deviate scores showed the number of conceptual questions was higher than expected and the number of mathematical questions was lower than expected. Since this paper focused on the conceptual questions in these chapters, it isn't surprising that a majority of these questions are based on the conceptual (KMT) standard. The reason the number of mathematical questions is lower than expected is because this study excluded the mathematical (calculation) questions and focused only on the conceptual questions related to these mathematical calculations.

Two-Way Associations. The test for two-way associations in a loglinear analysis is analogous to a chi-square test of homogeneity. Four of the two-way associations (BT × QP, BT × ST, QF × QP, and RP × ST) were found to be significant; one of these associations (BT × QP) was significant in both tests.

Book Type × Question Placement. For the college textbooks, 6% of the questions were in-chapter questions, 60% were end-of-chapter questions, and 34% were test-bank questions. For the high school books, 19% of the questions were in-chapter questions, 22% were end-of chapter questions, and 59% were test-bank questions. Although both loglinear tests showed a significant BT × QP association, each test identified different significant standard normal deviate scores.

When the Question Format variable was collapsed, the number of questions in the 'College/End-of-chapter' and the 'High school/In-chapter' cells were higher than expected and the number of questions in 'College/In-chapter' and the 'High school/End-of-chapter' cells were lower than expected. When the Standard variable was collapsed, the number of questions in the 'College/End-of-chapter' and the 'High school/Test-bank' cells were higher than expected and the number of questions in 'College/Test-bank' and the High school/End-of-chapter' cells were lower than expected. Taken together, these results suggest that college textbooks have a higher proportion of their questions at the end of the chapters (60%) while high school textbooks have a higher proportion of their questions in the book chapters and in the test banks (78%).

High school textbooks place more questions in the chapters to provide students with several examples showing them how to solve these problems; presumably, college students do not need as many worked-out examples. College textbooks, on the other hand, place more of their questions at the end of the book. This provides students with many examples to work on their own, which should help them take control of their learning by solving many chemistry problems like those that will appear on their examinations. Finally, high school textbooks have many more questions in the test bank, which provides instructors with many examples of problems to place on their own exams; it is probably true that most instructors who teach college chemistry are comfortable in writing their own questions for class examinations and don't need a lot of test-bank questions.

<u>Book Type × Standard</u>. For the college chemistry textbooks, 74% of the questions analyzed in this study related to the conceptual Arkansas standard and 26% related to the mathematical Arkansas standards. For the high school chemistry textbooks, 39% of the questions related to the conceptual Arkansas standard and 61% related to the

mathematical Arkansas standards. The normal deviate scores showed the number of 'College/Conceptual' and 'High school/Mathematical' questions were higher than expected and the number of 'College/Mathematical' and 'High school/Conceptual' questions were lower than expected.

High school chemistry textbooks tend to discuss the conceptual side of the mathematical gas law equations (Boyle's Law, Charles' Laws, etc.) more than college chemistry textbooks. One possible reason for this is since high school students are encountering the equations for the first time, textbook authors want to ensure that students have a grasp of the conceptual nature of using these equations. Hopefully, this would minimize calculation errors from these students. College-level textbook authors, on the other hand, may assume that if students are taking chemistry at the college level, they have taken one or more years of chemistry and should understand the conceptual nature of using these equations.

<u>Question Format × Question Placement</u>. All of the in-chapter questions (100%) and a large majority of the end-of-chapter questions (98%) were short-answer format. For the test-bank questions, however, only 17% were short answer. The normal deviate scores showed the number of 'In-chapter/Short answer', 'End-of-chapter/Short answer', and 'Test-bank/Multiple-choice' questions was higher than expected, while the number of 'In-chapter/Multiple-choice', 'End-of-chapter/Multiple-choice', and 'Test-bank/Short answer' questions was lower than expected.

There is no reason why textbook authors cannot place multiple-choice questions in or at the end of the chapters and there is no reason why test banks can't have more short-answer questions. This difference between the textbooks and test banks is arbitrary and perhaps it exists because the authors followed the "traditional" way of doing things. One reason why test banks may have many multiple-choice questions is because this format has been the accepted assessment format of several state or national assessment tools (No Child Left Behind assessment, Advanced Placement examinations, American Chemical Society examinations, etc.). However, if we want students to be successful on these types of examinations, then textbooks should provide students with more practice multiple-choice questions (especially at the end of the chapter), instead of just during their formal assessment activities.

Representation × Standard. For the questions related to the conceptual Arkansas standard, 31% were macroscopic, 62% were particulate, and 7% were symbolic. For the questions relating to the mathematical Arkansas standards, 43% were macroscopic, 1% was particulate, and 56% were symbolic. The normal deviate scores showed the number of 'Particulate/Conceptual', 'Macroscopic/Mathematical', and 'Symbolic/Mathematical' were higher than expected and the number of 'Particulate/Mathematical', 'Macroscopic/Conceptual', and 'Symbolic/Conceptual' were lower than expected.

The kinetic-molecular theory (the Arkansas conceptual standard) is an inherently particulate, non-mathematical theory. So it isn't surprising that most of the questions related to this theory were particulate in nature and very few were symbolic. Similarly, the mathematical Arkansas standards are related to calculations using gas laws and stoichiometry. So it makes sense that most of these questions were symbolic in nature and few were particulate. What is interesting about these data is that a substantial number of questions for both standards were macroscopic in nature. The macroscopic questions are pretty evenly split between the two standards (45% were conceptual and 55% were mathematical).

Three-Way Associations. Three-way associations are sometimes difficult to explain and researchers often create interaction (or association) plots of the data to help explain these associations. If there were no association among the variables in the plot, the individual lines would be parallel. The deviation of these lines from being parallel represents the associations of the variables in the plot. Each loglinear test in the study identified one significant three-way association. When the Question Format variable was collapsed, the BT × QP × RP association was significant and when the Standard variable was collapsed, the BT × QF × QP association was significant. It was observed that the Book Type and the Question Placement were part of both significant three-way associations.

<u>Book Type × Question Format × Question Placement</u>. In the college chemistry textbooks, none of the in-chapter and end-of-chapter questions (0%) were multiple-choice, while all of the test-bank questions were multiple-choice (100%). In the high school chemistry textbooks, none of the in-chapter questions (0%) and very few of the end-of-chapter questions (5%) were multiple-choice, while the majority of test-bank questions were multiple-choice (76%).

The normal deviate scores showed the number of 'College/End-of-chapter/Short-answer', 'College/Test-bank/Multiple-choice', 'High school/End-of-chapter/Multiple-choice', and 'High school/Test-bank/Short-answer' questions were higher than expected, while the number of 'College/End-of-chapter/Multiple-choice', 'College/Test-bank/Short-answer', 'High school/End-of-chapter/Short-answer', and 'High school/Test-Bank/Multiple-choice' questions were lower than expected

An interaction plot of these data appears in Figure 1. In this figure, the percent of multiple-choice questions in the high school and college books was plotted against the question placement (in-chapter, end-of-chapter, and test-bank). The deviation of these

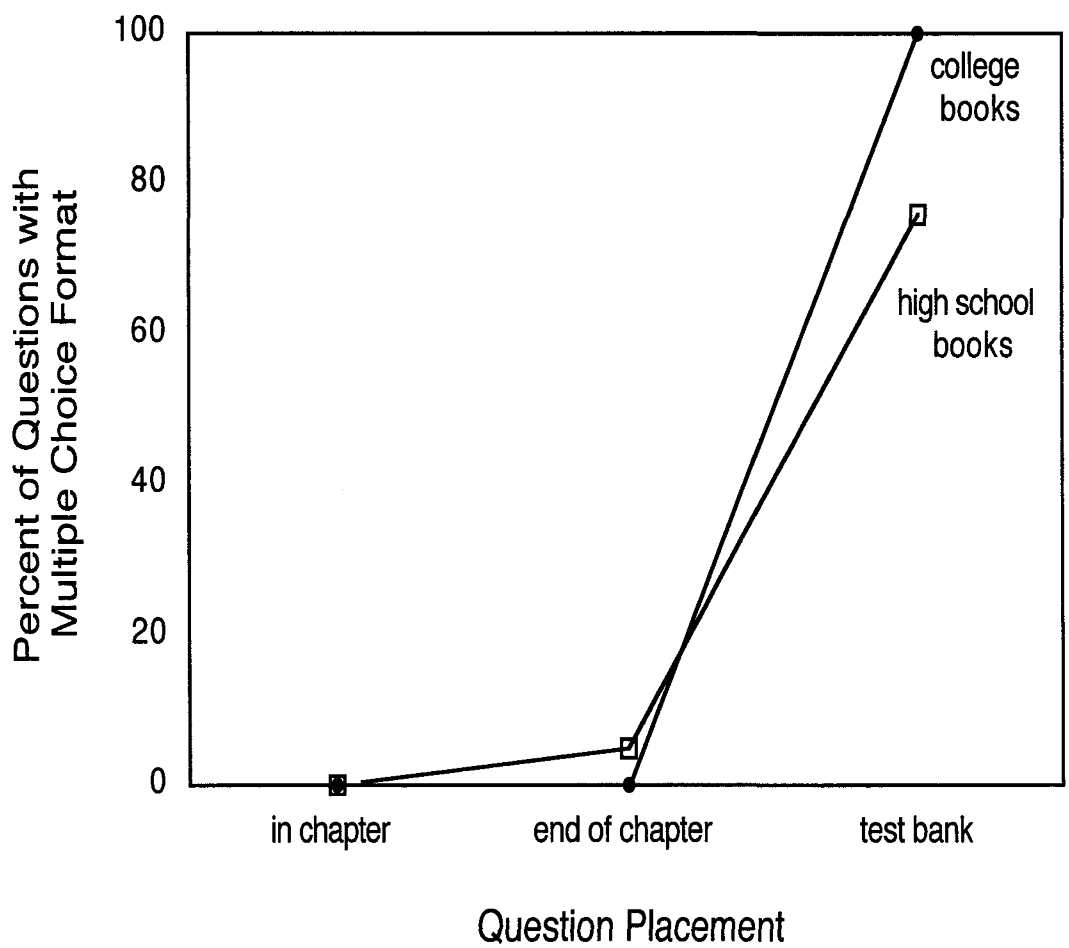

Figure 1. Interaction plot for the BT × QF × QP association.

two lines from being parallel supports the idea that the proportion of end-of-chapter multiple-choice questions was higher than predicted for the high school books and lower than predicted for the college books. The graph also shows that the proportion of the multiple-choice questions in the test banks was too high for the college books and too

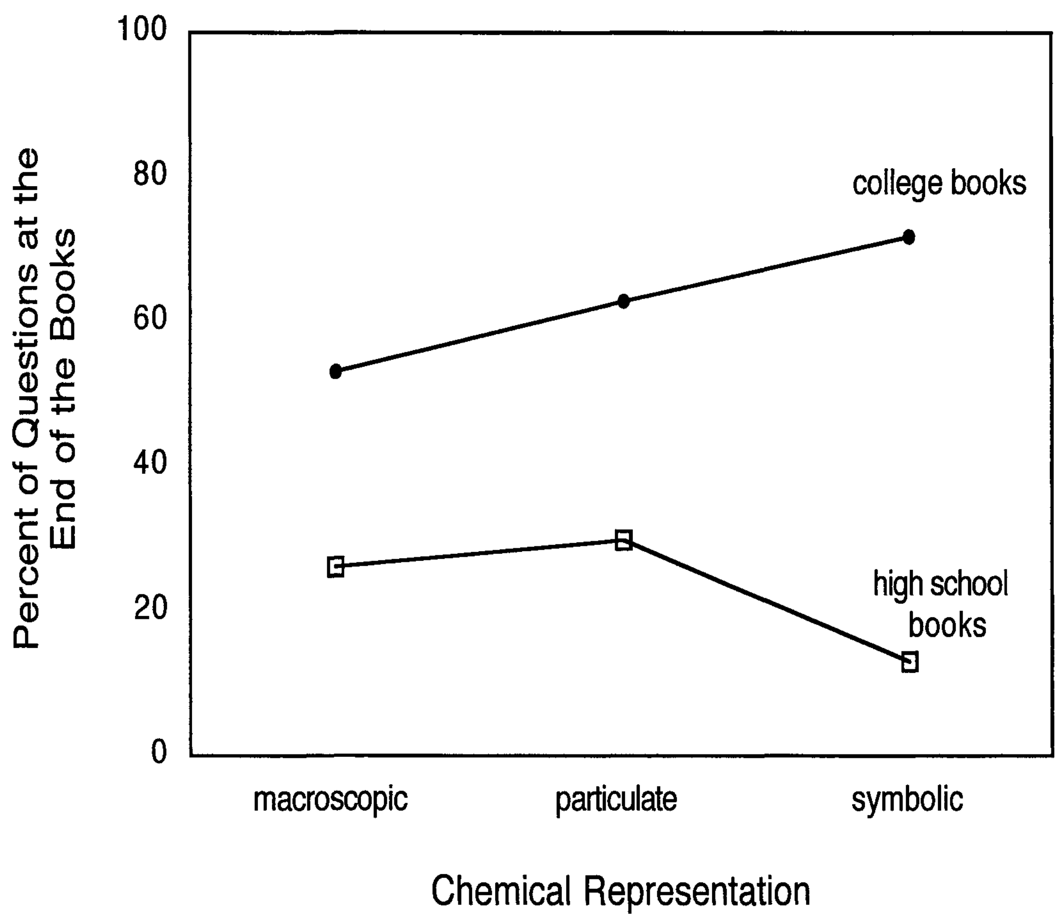

Figure 2. Interaction plot for the BT × QP × RP association.

low for the high school books. For whatever reasons, chemistry textbooks have traditionally been written with short-answer questions in and at the end of the chapters and with multiple-choice questions in the test banks. This significant association makes it clear that this trend is more pronounced in the college chemistry textbooks than in the high school chemistry textbooks.

Book Type × Question Placement × Representation. Although this association is statistically significant, none of the standard normal deviate scores were significant. The cells that had the largest magnitudes were the 'College/End-of-chapter/Symbolic' cell at +1.871 and the 'High School/End-of-chapter/Symbolic' cell at –1.871. An interaction plot of these data appears in Figure 2. In this figure, the percent of all questions appearing at the end of the chapters is plotted against the three representations for the college and high school textbooks. The deviation of these two lines from being parallel supports the idea that the 'College/End-of-chapter/Symbolic' frequency was higher than expected and the 'High School/End-of-chapter/Symbolic' frequency was lower than expected, even though these values were not significant.

In the college textbooks, 72% of the symbolic questions appeared at the end of the chapters; in the high school textbooks, only 13% of the symbolic questions appeared at the end of the chapters (67% of the symbolic questions in the high school books appeared in the test banks). Presumably, most of the symbolic questions in the college books appeared at the end of the chapters to give students more practice answering these questions so they would be ready for their exams. The greater number of symbolic questions in the high school test banks would give instructors a greater choice of questions to ask the students on their exams. It is interesting that this difference appeared only for the symbolic questions.

Conclusions

In this study, we compared the distribution of conceptual questions appearing in the gas law chapters of four high school and four college chemistry textbooks based on five variables—Book Type (high school, college), Question Format (multiple choice, short answer), Question Placement (in-chapter, end-of-chapter, test bank), Representation (macroscopic, particulate, symbolic), and Arkansas Science Framework Standards (conceptual, mathematical). Eleven significant associations among these variable were identified. The Book Type and the Question Placement variables appeared to have the greatest impact on the distribution of questions, as evidenced by the fact that they were part of seven of the eleven significant associations.

Differences in high school and college textbooks. The distribution of questions in the high school and college textbooks were very different. Compared to the college textbooks, the high school textbooks had more conceptual questions, a higher proportion of question within the chapters, a lower proportion of questions at the end of the chapters, a higher proportion of questions matching the Arkansas mathematical standards, and a lower proportion of symbolic-level questions at the end of the chapters. In addition, while both types of textbooks had more short answer questions within and at the end of the chapters and more multiple-choice questions in the test banks, this trend was more extreme for college textbooks.

Why is there such a difference in the way that college and high school chemistry textbooks ask questions? One explanation could be that college chemistry textbooks are geared toward students who have some background in chemistry, while high school chemistry textbooks are geared toward students taking chemistry for the first time. This could explain why high school chemistry textbooks have more questions than college chemistry textbooks and why they have a greater proportion of in-chapter questions than college chemistry textbooks—to provide students with more chances to answer chemistry questions and more opportunities to see examples of worked-out problems as they study chemistry. These differences might also say something about the perceived preparation of high school and college chemistry instructors. For example, high school chemistry textbooks may have been written with a higher proportion of questions in test banks compared to college chemistry textbooks to provide high school chemistry teachers with more choices for examination questions, under the assumption that college chemistry teachers would have better chemistry content knowledge and would be better able to write test questions on their own.

Differences in in-chapter, end-of-chapter, and test-bank questions. The distribution of questions in the gas law chapters, at the end of the chapters, and in the test banks was very different. There were more questions appearing at the end of the chapters and in the test banks compared to the number of questions within the chapters. High school textbooks had a higher proportion of their questions in the chapters and the test banks, while college textbooks had a higher proportion of questions at the end of the chapters. There was a higher proportion of short-answer questions in the chapters and at the end of the chapters and there was a higher proportion of multiple-choice questions in the test banks—and this trend was more extreme for college textbooks than high school textbooks.

Presumably, the goals of these three question types are different and this could explain the differences in question distribution. In-chapter questions are intended to show students how to solve chemistry problems. So, high school textbooks have more of these example problems because high school students are less familiar with the chemistry topics and would need more assistance from the book. Since the goal of these questions is to explain chemistry concepts, it makes sense that they would favor short-answer over multiple-choice format. Because these worked-out examples take up more space (which is a premium in textbooks), textbooks have fewer in-chapter questions compared to end-of-chapter and test-bank questions.

End-of-chapter questions are intended to give students opportunities to practice their problem-solving skills and to prepare them for course examinations. College chemistry textbooks have a higher proportion of their questions at the end of the chapters compared to high school chemistry textbooks. This could be explained by the idea that college chemistry courses value students' autonomy and responsibility in monitoring their own learning. So, college chemistry textbooks are more likely to provide several examples of the same questions at the end of the chapters to allow students to practice on their own until they decide that they understand the concepts. These goals, however, do not adequately explain why textbooks would provide mostly short-answer questions and almost no multiple-choice questions. This bias is also at odds with one of the end-of chapter goals (preparing students for course examinations) if their instructors give multiple-choice examinations, a very common practice. The lack of multiple-choice questions at the end of the chapters may also hinder students' performance on standardized assessments (like NCLB assessments, ACS examinations, or other standardized tests like SAT, ACT, MCAT, GRE, etc.).

Test-bank questions are intended to give chemistry instructors examples of questions for their examinations. High school chemistry textbooks have a higher proportion of questions in the test banks compared to college chemistry textbooks. It could be that the textbooks authors have assumed that high school teachers are less comfortable in writing their own exam questions, that they are busier and have less time to write these questions, or that they teach more sections of the same course during the same semester so they would need more examples of questions to pick from. As with end-of-chapter questions, the goals of test bank questions do not adequately explain why textbooks provide mostly multiple-choice questions and almost no short answer questions. This lack of short-answer questions limits the usefulness of test banks for teachers who do not use multiple-choice questions. Worse yet, the bias toward multiple-choice questions in test banks can force course assessments to be solely in the multiple-choice format (i.e., if teachers want to use the test bank to write their examination, the test will have to be mostly multiple-choice).

Implications for textbook authors. The implicit assumption in this study is that ideally there would be no associations among any of the variables (i.e., the distribution of question types would be completely homogeneous). However, this may not be optimal. For example, considering the RP × ST association it may not make sense to try to write more symbolic questions about the conceptual standard (kinetic molecular theory) or more particulate questions about the mathematical standards (gas laws and stoichiometry calculations). It also wouldn't make sense to write high school and college textbooks identically if the populations of students they are intended for are not identical. We would suggest, however, that textbook authors think about the assumptions (conscious or otherwise) that guide their placement of questions in the textbooks. This is especially important with respect to the Book Type (high school, college) and Question Placement (in-chapter, end-of-chapter, and test-bank) since these variables appeared in most of the associations identified in this study. We would also urge textbook (and test-bank) authors to consider placing more multiple-choice questions at the end of the chapters and more short-answer questions in the test banks. The QF × QP association identified in this study seems very arbitrary and we believe that students and instructors would benefit from eliminating this association.

Implications for instructors. This study started by looking at whether chemistry teachers should use high school or college chemistry textbooks to teach an AP chemistry course. This study showed that high school and college chemistry textbooks are very different with respect to their distribution of questions within the gas law chapters. We would urge AP chemistry teachers deciding what type of textbook to use to analyze the goals of their course and the characteristics and needs of their students before choosing a textbook. This study also points out deficiencies in the conceptual questions asked in high school and college textbooks and we would urge chemistry instructors to pay attention to these deficiencies. For example, if students in these classes were expected to take assessments using multiple-choice format (NCLB assessments, AP test, ACS exams, SAT, ACT, GRE, MCAT, etc.), instructors should provide students with examples of multiple-choice chemistry problems to practice in class and when they are studying on their own to compensate for the lack of multiple-choice questions in and at the end of the textbook chapters.

Implications for future studies. In this study, we compared the distribution of conceptual questions in the gas law chapters of several high school and college textbooks. We are currently working on another manuscript to describe the distribution of mathematical (calculation) questions in the gas law chapters of the same high school and college textbooks. This analysis could be expanded to other chapters in chemistry textbooks or even to chapters in other science or non-science textbooks. We chose gas law chapters in the chemistry textbooks because they were likely to have lots of questions at the macroscopic, particulate, and symbolic levels. It would be interesting to see how the distribution of questions would be different in predominantly symbolic (mathematical) chapters like stoichiometry or thermochemistry, in predominantly particulate chapters like Lewis-dot structures and VSEPR, and in predominantly macroscopic chapters like the descriptive chemistry of main-group elements and transition metals.

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CHAPTER 3. ANALYZING THE DISTRIBUTION OF GAS LAW QUESTIONS IN CHEMISTRY TEXTBOOKS—MATHEMATICAL QUESTIONS

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Abstract

The mathematical gas law questions from four high school and four college chemistry textbooks were analyzed for associations among five variables. These variables included Bloom's Taxonomy (higher-order, lower-order), Book Type (high school, college), Question Format (multiple-choice, problem), Question Placement (in-chapter, end-of-chapter, test bank), and Arkansas Science Framework Standards (pressure conversion, gas laws, stoichiometry). All five variables appeared in the 11 significant associations, but Question Placement appeared in the most associations (7 of the 11). In this paper, we discuss possible reasons why the distribution of questions would be different for the in-chapter, end-of-chapter, and test-bank questions. This paper ends with a summary of the results of this study and a previous one involving the conceptual questions from the gas law chapters of the same eight textbooks.

Introduction

For many high school and college chemistry courses, the textbook dictates the chemical concepts taught and the order in which they are taught. Textbooks are used in 90% of the secondary science courses and are responsible for 75% or more the content covered in class *(1)*, and have become encyclopedias of science facts that encourage teachers and students to focus on memorization *(2-4)*. Teachers often view textbooks as the sole source of information that determine the content to be covered and students and parents expect science textbooks to be used as the basis of all school assignments *(5-7)*. Textbooks have started to play an even bigger role in assessment since the implementation of No Child Left Behind (NCLB) in the K-12 classrooms *(8-10)*.

Articles about textbooks have been very popular in this *Journal*, appearing in every decade since its inception *(11-24)*. While the earliest articles focused on educational issues associated with picking textbooks *(11-13)*, most recent articles have focused on improved ways of teaching specific content material *(14, 18, 20, 22, 23)* or on specific textbook errors and the possible misconception that could arise from these errors *(15-17, 19, 21, 22, 24)*. Only one article from 1935 *(12)* analyzed the problems appearing in chemistry textbooks, focusing on the percentage of the entire book occupied by calculation questions and the types of mathematical skills needed to solve these questions.

The goal of this study was to evaluate how high-school and college chemistry textbooks help high school students enrolled in Advanced Placement (AP) classes meet the Arkansas State Frameworks Standards and how they prepare students for the end-of-year NCLB test. Since NCLB focuses on students' performance and has provisions to hold schools, districts, and states accountable for their students' performance, we focused our analysis on the assessment questions used in these textbooks. In our first paper *(25)*, we focused on the non-mathematical (conceptual) questions; in this paper, we are focusing on the mathematical (calculation) questions.

We chose to analyze the gas law chapters in four high school and four college (AP) books because these chapters contain a variety of questions based on different factors: questions within the chapters, at the end of the chapters, and in the test banks; higher- and lower-order questions based on Bloom's taxonomy *(26-28)*; and multiple-choice and problem format *(29, 30)*. We also linked these questions to the three gas law standards based on the Arkansas Science Framework Standards *(31)*.

We analyzed each mathematical question based on the five parameters described above. The research question for this study was: Are there any significant associations among the five variables in this study? The significant associations identified were then analyzed to explain any differences.

Methods

Data Collection. The in-chapter, end-of-chapter, and test-bank questions of the gas law chapters of four high school and four college chemistry textbooks were reviewed and analyzed. The high school textbooks and their test banks used in this study were *Chemistry: Matter and Change (32, 33)*, *Chemistry: Concepts and Applications (34, 35)*, *Chemistry (36, 37)*, and *Modern Chemistry (38, 39)*. The college chemistry textbooks and test-banks used were *Chemistry, 6th edition, (40, 41)*, *Chemistry: The Central Science, 10th edition, (42, 43)*, *Chemistry: Principles and Reactions, 4th edition, (44, 45)*, and

Introductory Chemistry: A Foundation, 5th edition, (46, 47). These books were chosen because they were approved for use in high school/Advanced Placement chemistry courses by the Arkansas State Board of Education.

In addition to the categories of Book type (BT) and Question Placement (QP), each part of the questions in the textbooks and test-banks was categorized according to three criteria: Bloom's Taxonomy (BL), Question Format (QP), and Standards (ST) from the Arkansas Science Framework Standards.

The questions were categorized according to their level of Bloom's Taxonomy. Instead of focusing on all six categories originally proposed by Bloom *(26)*, we decided to focus on lower-order cognitive skills (LOCS) and higher-order cognitive skills (HOCS). According to Zoller and Lubezky *(28)*, LOCS questions require simple recall and information or a simple application of known theories or knowledge to familiar situations and context. LOCS problems can also be problems involving algorithmic processes already known by the student. Zoller and Lubezky defined HOCS problems as being unfamiliar to the student and requiring more than simple recall and application. These questions often require analysis and synthesis capabilities as well as making connections and evaluative thinking on the part of the student. HOCS problems also include the application of known theories or knowledge to unfamiliar situations.

The Question Format categories originally included multiple-choice, true-false, matching, and problems. We collapsed the multiple-choice, true-false, and matching questions into one category (multiple-choice) since they all represent questions where students have been given a choice of answers. A problem (calculation) question is one that can be answered by mathematical manipulation of the data given in the question.

The Arkansas Science Frameworks Standards *(31)* were revised in 2005 and have three standards based on the topics of kinetic molecular theory and the gas laws. Standard 16A concerns the behavior of gas particles using the kinetic-molecular theory. Since this standard is inherently conceptual (non-mathematical), questions related to this standard do not appear in this study. Standard 17 relates to the mathematical relationships between temperature, pressure, volume, and moles of a gas (the 'gas law' standard in this study). Both Standards 16B and 18 concern the mathematical relationship between the stoichiometric mass and the properties of a gas (volume, pressure, temperature, and moles) in chemical reactions (the 'stoichiometry' standard). The third standard described in this paper ('pressure conversion') does not appear in the Arkansas science standards, but these calculations were prominent in each of the textbooks analyzed and were included in this study.

Each question in the gas law chapters of the eight chemistry textbooks and test banks was categorized by the first author. The second author categorized the end-of-chapter questions for *Chemistry: The Central Science (42)*. The results were compared and the inter-rater reliability was 0.86. The authors discussed all discrepancies and agreed how to categorize any vague questions. A second set of questions from another textbook was compared and the inter-rater reliability for the in-chapter questions in *Modern Chemistry (43)* was 0.96.

Data Analysis. In this study, each part of every question ($N = 1573$) was classified according to the five categories and the frequencies (numbers) of questions with the same values for the five independent variables were tallied. These nonparametric frequency data were analyzed using Loglinear Analysis *(48)*, which is an extension of the statistical method of Multiway Frequency Analysis *(49)*.

We used the LOGIN function of the statistical program SYSTAT to perform the loglinear analyses in this study *(50)*. The loglinear analyses were performed using a saturated model, in which all possible associations were tested. With the saturated model, the highest-order association is tested first. Then, the next highest-order associations are tested with the effect of the highest-order association removed (partialed out). The process continues from highest- to lowest-order associations with the effects of all higher-order associations removed before a test is performed. Because of the partialing effect, the results of the two-way association test between two variables may be very different than the chi-square test of independence performed between these two variables because the chi-square test does not correct for higher-order associations.

Multiway frequency analyses make no assumptions about population distributions and are remarkably free of limitations *(48)*. However, researcher should be concerned about having too many variables since it can be very difficult to explain (or understand) three-, four-, or higher-order associations. For this reason, we separated the mathematical and conceptual questions into two studies, and for the mathematical questions in this study, we performed two loglinear analyses containing four variables each. In the first analysis, we collapsed the Question Format variable because it caused many cells with zero frequencies. The frequency table and the results for this loglinear analysis appear in Tables 1 and 2, respectively.

Bloom's Taxonomy	Book Type	Question Placement	Standard gas laws	pressure conversion	stoichiometry
higher-order	college	in-chapter	30	0	14
		end-of-chapter	183	44	77
		test-bank	112	2	52
lower-order		in-chapter	47	21	0
		end-of-chapter	225	62	4
		test-bank	77	21	3
higher-order	high school	in-chapter	60	0	23
		end-of-chapter	55	0	40
		test-bank	42	9	6
lower-order		in-chapter	104	15	3
		end-of-chapter	106	18	2
		test-bank	95	7	14

Table 1. Observed Frequency Data for the Loglinear Comparison with Question Format Collapsed.

In the second analysis, we collapsed the Bloom's Taxonomy variable because in the complete five-way test (not described in this study), it showed the fewest associations with the Questions Format variable. This was important because performing the two smaller tests prevented us from testing for any associations involving both Question Format and Bloom's Taxonomy. The frequency table and the results for the second loglinear analysis appear in Tables 3 and 4, respectively.

Source	df	χ^2 value	p value
Bloom's Taxonomy (BL)	1	0.62	0.43
Book Type (BT)	1	3.31	0.07
Question Placement (QP)	2	19.95	0.00[a]
Standard (ST)	2	852.47	0.00[a]
BL × BT	1	4.51	0.04[a]
BL × QP	2	1.37	0.50
BL × ST	2	154.26	0.00[a]
BT × QP	2	27.46	0.00[a]
BT × ST	2	3.57	0.17
QP × ST	4	3.58	0.47
BL × BT × QP	2	0.92	0.63
BL × BT × ST	2	3.79	0.15
BL × QP × ST	4	21.46	0.00[a]
BT × QP × ST	4	15.15	0.00[a]
BL × BT × QP × ST	4	38.01	0.00[a]

[a]$p<0.05$ corresponds to a significant association between these variables.

Table 2. Loglinear Analysis Output for the Associations between the Independent Variables with Question Format Collapsed.

Book Type	Format	Question Placement	Standard		
			gas laws	pressure conversion	stoichiometry
college	multiple-choice	in-chapter	0	0	0
		end-of-chapter	0	0	0
		test-bank	180	23	55
	problem	in-chapter	77	21	14
		end-of-chapter	408	106	81
		test-bank	9	0	0
high school	multiple-choice	in-chapter	0	0	0
		end-of-chapter	0	0	0
		test-bank	87	6	16
	problem	in-chapter	164	15	26
		end-of-chapter	161	18	42
		test-bank	50	10	4

Table 3. Observed Frequency Data for the Loglinear Comparison with Bloom's Taxonomy Collapsed.

Tabachnick and Fidell *(48)* describe four practical issues affecting the power of loglinear results. First, all of the categories are required to be mutually exclusive, so that each question appears in only one cell. This requirement has been met in this study. Second, there should be at least five times as many questions as cells in the study; in both

Source	*df*	χ^2 value	*p* value
Book Type (BT)	1	0.07	0.80
Question Format (QF)	1	36.58	0.00[a]
Question Placement (QP)	2	8.67	0.01[a]
Standard (ST)	1	10.63	0.00[a]
BT × QF	1	2.06	0.15
BT × QP	2	2.90	0.23
BT × ST	2	0.09	0.96
QF × QP	2	354.61	0.00[a]
QF × ST	2	5.24	0.07
QP × ST	4	7.29	0.12
BT × QP × ST	4	0.58	0.97
BT × QF × QP	2	11.72	0.00[a]
BT × QF × ST	2	0.09	0.96
QF × QP × ST	4	1.77	0.78
BT × QF × QP × ST	4	1.35	0.85

[a] $p<0.05$ corresponds to a significant association between these variables.

Table 4. Loglinear Analysis Output for the Associations between the Independent Variables with Bloom's Taxonomy Collapsed.

loglinear analyses in this study, there are an average of 43.69 questions per cell. Third, when cases are rare (less than five) the marginal frequencies may not be evenly distributed. The expected cell frequencies for all two-way associations should be examined to assure that all are greater than zero, and no more than 20% are less than five. When the Question Format was collapsed, there were no cells below five. When the Bloom's Taxonomy was collapsed, 2 of 37 cells (5%) had frequencies of zero, but no other cells had frequencies less than five. The two zero cells were found in the QF × QP association—'Multiple-choice/In-chapter' and 'Multiple-choice/End-of-chapter'. The only way to address this loss of power would be to analyze more textbooks *(50)*. However, it is unlikely that analyzing more textbooks will eliminate these zero entries since very few textbooks use multiple-choice questions within the text or at the end of the chapters. Therefore, we have decided to accept the loss of power associated with having zero entries in these two cells. Fourth, when performing non-standard analysis, there may be substantial differences between observed and expected frequencies that make it impossible for the proposed model to adequately fit the data. This is not an issue when performing saturated tests.

Results and Discussion

The results of the loglinear analysis with the Question Format variable collapsed showed two significant one-way associations (QP, ST), three significant two-way associations (BL × BT, BL × ST, and BT × QP), two significant three-way associations (BL × QP × ST and BT × QP × ST), and one significant four-way association (BL × BT × QP × ST). For the loglinear analysis with the Bloom's Taxonomy variable collapsed, there were three significant one-way associations (QF, QP, and ST), one significant two-way association (QF × QP), and one significant three-way association (BT × QF × QP).

For each association test, SYSTAT calculates standard normal deviate scores for each cell. These values represent *z* scores that determine the influence of each cell on the overall effect *(55)*. A standard deviate score above +1.96 means that the observed frequency of a cell is significantly higher (at the 0.05 level) than predicted if the questions were distributed homogeneously and a standard deviate score below −1.96 means that the observed frequency of a cell is significantly lower (at the 0.05 level) than predicted if the questions were distributed homogeneously.

One-Way Associations. The test for one-way associations in a loglinear analysis is analogous to a chi-square goodness-of-fit test, which tests whether the cell frequencies within each variable are equal. Three of the variables (QF, QP, and ST) showed significant one-way associations; two of these associations (QP and ST) were significant in both tests. Although the one-way association for the Book Type variable was not significant in either test, we will briefly discuss this association.

<u>Book Type</u>. Although the one-way association for the Book Type variable was found to be significant in the previous study involving conceptual questions *(25)*, it was not significant for the mathematical questions in this study (p = 0.07 and 0.80). In the test where the Question Format variable was collapsed, the normal standard deviates imply that the number of questions in the college books (N = 974) was higher than expected (+1.98) and the number of questions in the high school books (N = 599) was lower than expected (-1.98), even though the overall association was not significant. Although this does not represent a statistically significant difference, we believe that this difference has

a real practical significance—the college books averaged 243 mathematical questions, while the high school books average only 150 questions.

We believe the reason that this one-way association is not significant in this study is a result of the way the computer performs LOGLIN calculations. When the one-way associations were calculated, the computer has already partialed out the effects due the higher-order (four-, three-, and two-way) associations. The chi-square test of goodness-of-fit performed on these data (which would be equivalent to the one-way association if the higher-order effects were not partialed out) was $\chi^2(1) = 89.40, p < 0.01$. The results of this study involving the mathematical questions and the previous study involving the conceptual questions showed that the high school books have more conceptual questions and fewer mathematical questions, while the reverse is true of the college books. Since high school textbooks are used by students learning chemistry for the first time, it makes sense that they would focus on concepts over calculations. The fact that college textbooks focus on calculations over concepts may represent the assumption that students should already know the concepts, or perhaps the idea that college instructors value students' abilities to answer mathematical questions over conceptual ones.

Question Format. The eight chemistry textbooks had a total of 367 multiple-choice questions (46 per book) and 1206 problem questions (151 per book). The standard deviate scores showed the number of problem questions was higher the expected and the number of multiple-choice questions was lower than expected. This difference could be explained by the fact that the multiple-choice questions only appeared in the test banks, but the problem format appeared in all three places. The lack of multiple-choice questions could be because authors must put some thought into writing three or four good distractors, and this takes time. It is also possible that textbook authors wrote more calculation questions because they believe that it is important for students to show the method they used to solve problems—both for correcting incorrect student calculations and for evaluation purposes on examinations. For these reasons, it is not surprising that textbook authors would write more calculation questions than multiple-choice questions.

Question Placement. There were 317 questions (20% of the total) within the textbook chapters, 816 questions (52% of the total) at the end of the chapters, and 440 questions (28% of the total) in the text banks. When the Question Format variable was collapsed, the standard deviate scores showed the number of end-of-chapter questions was higher than expected and the number of in-chapter questions was lower than expected. When Bloom's Taxonomy variable was collapsed, the standard deviate scores showed the number of test-bank questions was higher than expected and the number of in-chapter questions was lower than expected. In-chapter questions take up a lot of space because they show detailed explanations of how to solve the problem along with the question. Since in-chapter questions take a lot of space, most textbooks contain very few of them. End-of-chapter and test-bank questions, on the other hand, take up less space so more of them can appear in the same space. The larger number of end-of-chapter questions provides students more examples to practice a specific type of calculation. The larger number of test-bank questions allows instructors greater flexibility in choosing questions for examinations.

Standard. There were a total of 1136 questions (72% of the total) based on gas laws, 199 questions (13% of the total) based on pressure conversion, and 238 questions (11% of the total) based on stoichiometry. When the Question Format variable was collapsed, the standard deviate scores showed the number of gas law questions was higher than expected and the number of pressure conversion and stoichiometry questions was lower than expected. When Bloom's Taxonomy variable was collapsed, the standard deviate scores showed the number of gas law questions was higher than expected and the number of pressure conversion questions was lower than expected. The pressure conversion and the stoichiometry questions generally appear in a single section of the textbooks and represent a single type of calculation. Gas law questions, on the other hand, appear in several different sections of the textbook (individual gas laws, the ideal gas law, before-and-after calculations using the combined gas law, partial pressures, etc.) and often use more than one mathematical formula. So, it is not surprising that the collection of calculations falling under the gas laws standard would outnumber the pressure conversion and stoichiometry questions.

Two-Way Associations. The test for two-way associations in a loglinear analysis is analogous to a chi-square test of homogeneity. When the Question Format was collapsed, there were three significant two-way associations (BL × BT, BL × ST, and BT × QP). When Bloom's Taxonomy was collapsed, there was one significant two-way association (QF × QP).

Bloom's Taxonomy × Book Type. The high school textbooks had 364 lower-order questions and 235 higher-order questions, while the college textbooks had 460 lower-order questions and 514 higher-order questions. Higher-order level questions represented 53% of the questions found in college textbooks and 39% of the questions found in high school textbooks. The normal deviate scores showed the number of questions in the 'Higher-order/College' and the 'Lower-order/High school' was higher than expected and the number of questions in the 'Lower-order/College' and 'Higher-order/High school' was lower than expected.

High school textbooks had a higher proportion of LOCS questions requiring only one concept while college textbooks had a higher proportion of HOCS questions requiring multiple concepts or steps. Since the high school books are intended for students who may be learning chemistry for the first time, it makes sense that these books would focus on simple one-step calculation. College books, on the other hand, are usually intended for students who have previously studied chemistry and who should be better prepared to handle complex multi-step calculations.

Bloom's Taxonomy × Standard. The proportions of higher-order questions for the three standards were very different in this study—42% of the gas law questions, 28% of the pressure conversion questions, 89% of the stoichiometry questions were higher-order questions. The normal deviate scores showed the number of 'Higher-order/Stoichiometry' and 'Lower-order/Pressure conversion' questions was higher than expected, while the number of 'Higher-order/Pressure conversion' and 'Lower-order/Stoichiometry' questions was lower than expected.

Most pressure conversion questions involve a single calculation to convert from one pressure unit to another. It is possible for these calculations to require two or more unit conversions (e.g., mm Hg to atm and then atm to kPa, or lb to N and ft to m), but these kinds of problems are rare. On the other hand, stoichiometry problems involving gas laws almost always involve at least two steps—using the ideal gas law to determine the number of gas particles and using chemical reactions and stoichiometry to convert the number of gas particle to grams of another chemical. While it is possible for a question to focus on only one of these steps (which would make the question lower-order), it is rare—questions not involving the stoichiometry step would be classified as 'gas law' calculations, and questions not involving the gas law step would appear in the stoichiometry chapter and not in this chapter.

Book Type × Question Placement. For the college textbooks, 11% of the questions were in-chapter questions, 61% were end-of-chapter questions, and 27% were test-bank questions. For the high school books, 34% were in-chapter questions, 37% were end-of-chapter questions, and 29% were test-bank questions. Based on the normal deviate scores, the number of 'College/End-of-chapter' and the 'High school/In-chapter' questions was higher than expected and the number of 'College/In-chapter' and the 'High school/End-of-chapter' questions was lower than expected.

Since high school textbooks are intended for students who are studying chemistry for the first time, it's not surprising that these books would have more questions in the chapters to provide students with several examples showing how to solve these problems. Assuming that college students have already studied chemistry and have performed these calculations in the past, they would not need as many worked-out examples within the chapters. Presumably, college textbooks place more of their questions at the end of the book to provide students with more examples to work on their own, which would help them prepare for their college chemistry examinations. This is consistent with many college instructors' beliefs that college students should be personally responsible for monitoring their learning, including their ability to perform calculations that will appear on their examinations.

Question Format × Question Placement. None (0%) of the in-chapter or end-of-chapter questions were multiple-choice, while 83% of the test-bank questions were multiple-choice. The normal deviate scores showed the number of 'Problem/In-chapter', 'Problem/End-of-chapter', and 'Multiple-choice/Test bank' questions was higher than expected, while the number of 'Multiple-choice/In-chapter', 'Multiple-choice/End-of-chapter', and 'Problem/Test bank' questions was lower than expected.

It is certainly possible for textbook authors to write multiple-choice questions within or at the end of the chapters and they could easily write test-bank questions in the problem format. This difference between the chapters and the test banks is arbitrary and may exist based on tradition (i.e., that's the way it's always been). Since the multiple-choice format is traditionally used for state and national assessment tools (No Child Left Behind assessment, Advanced Placement examinations, American Chemical Society examinations, etc.), authors may have decided to include multiple-choice questions in the test banks. However, if students are to be successful on these examinations, then textbooks should provide them with more multiple-choice questions to practice, especially at the end of the chapters. And, if examinations are intended to assess students' skills and knowledge, then they need to provide multiple format options for students to demonstrate their understanding of chemistry concepts.

Three-Way Associations. Three-way associations are sometimes difficult to fully explain and researchers often create interaction (or association) plots to help explain these associations. If the variables in the plot are not associated, then the individual lines would be parallel. The deviation of these lines from being parallel represents the associations of the variables in the plot. When the Question Format variable was collapsed, the BL × QP

× ST and the BT × QP × ST associations were found to be significant and when the Bloom's Taxonomy variable was collapsed, the BT × QF × QP association was found to be significant.

Bloom's Taxonomy × Question Placement × Standard. The normal deviate scores showed the number of 'Lower-order/In-chapter/Pressure conversion', 'Lower-order/Test bank/Stoichiometry', and 'Higher-order/Test bank/Pressure conversion' questions was higher than expected, while the number of 'Higher-order/In-chapter/Pressure conversion', 'Higher-order/Test bank/Stoichiometry', and 'Lower-order/Test bank/Pressure Conversion' questions was lower than expected. A plot of these data appears in Figure 1, in which the percent of higher-order questions is plotted against the three Arkansas Science Standards for the in-chapter, end-of-chapter, and test bank sections. Based on the normal deviate scores, the 'In-chapter/Pressure conversion' and the 'Test bank/Stoichiometry' points should be higher and the 'Test bank/Pressure conversion point' should be lower in the figure.

It is clear from the data that there should be more higher-order pressure conversion questions within the textbook chapters. The lack of higher-order pressure conversion questions in the chapters could be because textbook authors decided to focus on simpler (lower-order) examples when introducing these calculations to students, saving the higher-order pressure conversion calculations for the end of the chapters and test banks. For the test bank questions, there were more higher-order pressure conversion questions and fewer higher-order stoichiometry questions than expected. The reason for these deviations could be that test bank authors are providing instructors with a balance of higher- and lower-order questions on each topic. For example, although the

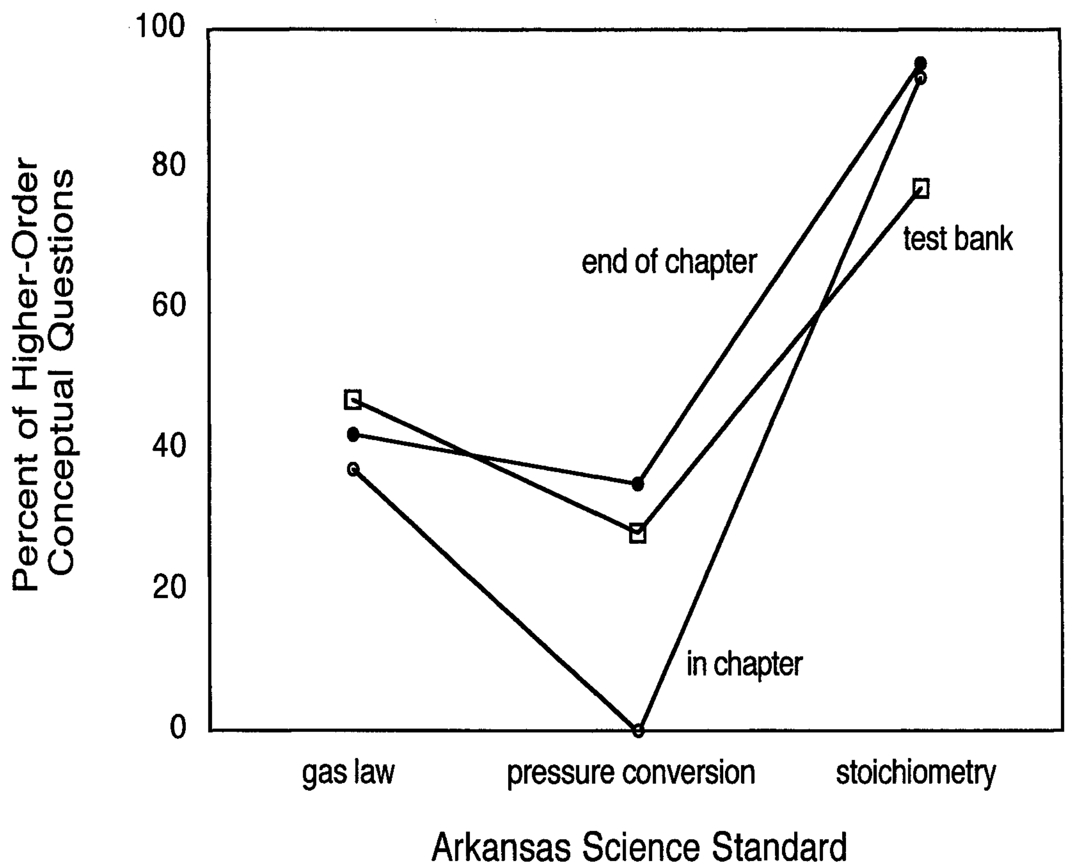

Figure 1. Interaction plot for the BL × QP × ST association.

stoichiometry questions in and at the end of the textbooks were more than 90% higher-order, the test-bank questions were only 77% higher-order—the extra lower order stoichiometry questions would allow instructors some choice in choosing lower-order stoichiometry questions.

Book type × Question Format × Question Placement. In the college chemistry textbooks, none of the in-chapter or end-of-chapter questions (0%) were multiple-choice questions, while a large majority (95%) of the test-bank questions was multiple-choice. In the high school chemistry textbooks, none of the in-chapter or end-of-chapter questions (0%) were multiple-choice questions, while 60% of the test-bank questions were multiple-choice questions. The normal deviate scores showed the number of 'College/Problem/End-of-chapter', 'College/Multiple-choice/Test-bank', 'High school/Multiple-choice/End-of-chapter', and 'High school/Problem/Test-bank' questions was higher than expected while the number of 'College/Multiple-choice/End-of-chapter', 'College/Problem/Test-bank', 'High School/Problem/End-of-chapter', and 'High School/Multiple Choice/Test-bank' questions was lower than expected.

A plot of the data associated with this test appears in Figure 2. In this figure, the percent of multiple-choice questions was plotted against the question placement for both the college and high school textbooks. Although the distribution of end-of-chapter questions is significantly different, these values are 0% multiple-choice for both book types. The real difference is that the college books have too many multiple-choice questions and the high school books have too few multiple-choice questions in the test banks. For whatever reason, chemistry textbooks have traditionally been written with short-answer questions in and at the end of the individual chapters and with multiple-choice questions in the test banks. This significant association makes it clear that this trend is more pronounced in college chemistry textbooks than in high school chemistry textbooks.

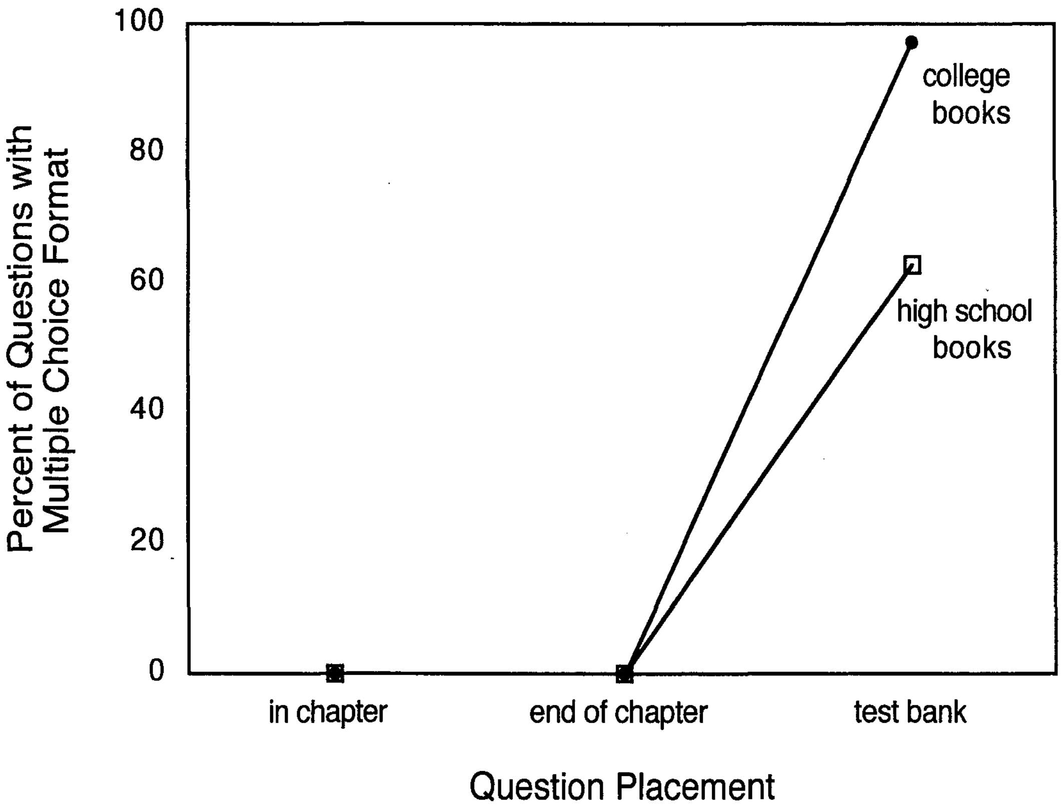

Figure 2. Interaction plot for the BT × QF × QP association.

Book Type × Question Placement × Standard. In this association, the number of 'High school/Test bank/Pressure conversion' questions was higher than expected, while the number of 'College/Test bank/Pressure conversion' questions was lower than expected. The plot of the data associated with this test, which appears in Figure 3, shows the percent of questions appearing in college textbooks plotted against the three Arkansas Science Standards for the three question placement sections. The in-chapter and end-of-chapter lines appear to be parallel (no associations), but the test bank line deviates from parallel because the college books have fewer pressure conversion questions than expected. Pressure conversion questions involve the simplest calculations (unit conversions) among the three standards. Perhaps the reason for the different distribution of these questions in high school and college books is that the test bank authors have assumed that high school instructors would be more likely to ask their students to solve simpler (lower-order) pressure conversion questions than college instructors.

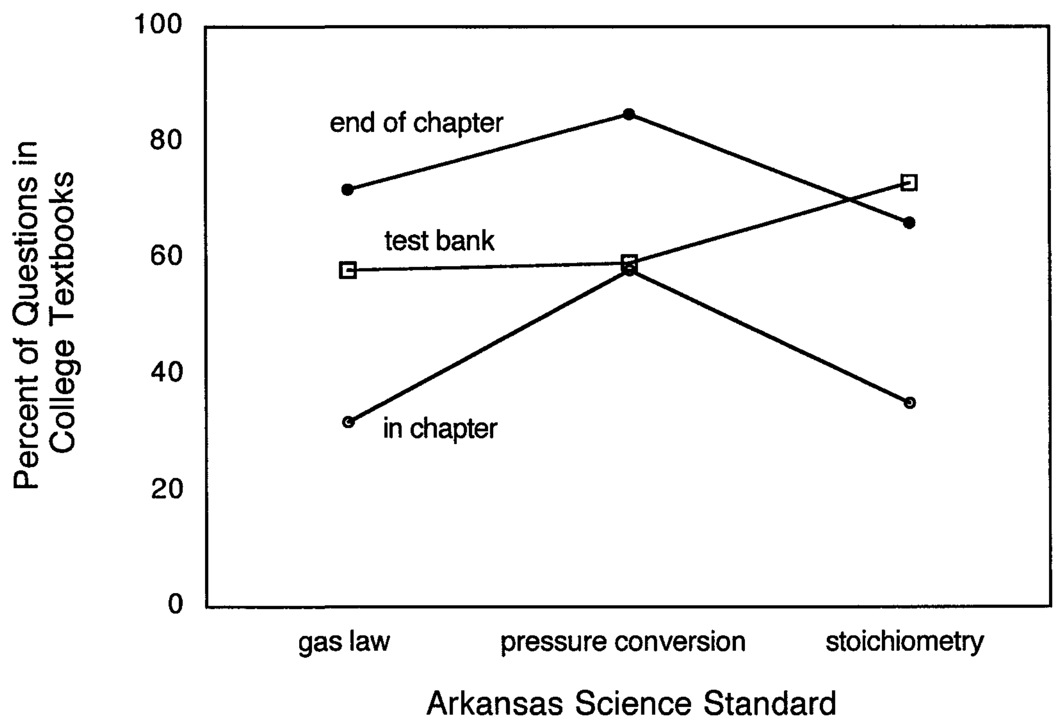

Figure 3. Interaction plot for the BT × QP × ST association.

Four-Way Associations. As with the three-way associations, four-way associations are difficult to fully explain and researchers tend to focus on interaction plots to explain these associations. When the Question Format variable was collapsed, the BL × BT × QP × ST association was found to be significant.

Bloom's Taxonomy × Book Type × Question Placement × Standard. The interaction plots for this association appear in Figure 4. In Figure 4a, the percent of higher-order questions appearing in each section (in-chapter, end-of-chapter, and test-bank) was plotted against the Arkansas Science Standards for high school textbooks; Figure 4b shows the same data for the college textbooks. According to the normal deviate scores, the number of 'Higher-order/College/End-of-chapter/Pressure conversion', 'Higher-order/College/Test-bank/Stoichiometry', 'Lower-order/College/End-of-chapter/Stoichiometry', 'Lower-order/College/Test-bank/Pressure conversion', 'Higher-order/High school/End-of-chapter/Stoichiometry', 'Higher-order/High school/Test-bank/Pressure conversion', 'Lower-order/High school/End-of-chapter/Pressure conversion' and 'Lower-order/High school/Test-bank/Stoichiometry' was higher than expected. The number of 'Lower-order/College/End-of-chapter/Pressure conversion', 'Lower-order/College/Test-bank/Stoichiometry', 'Higher-order/College/End-of-chapter/Stoichiometry', 'Higher-order/College/Test-bank/Pressure conversion', 'Lower-order/High school/End-of-chapter/Stoichiometry', 'Lower-order/High school/Test-bank/Pressure conversion', 'Higher-order/High school/End-of-chapter/Pressure conversion', and 'Higher-order/High school/Test-bank/Stoichiometry' was lower than expected.

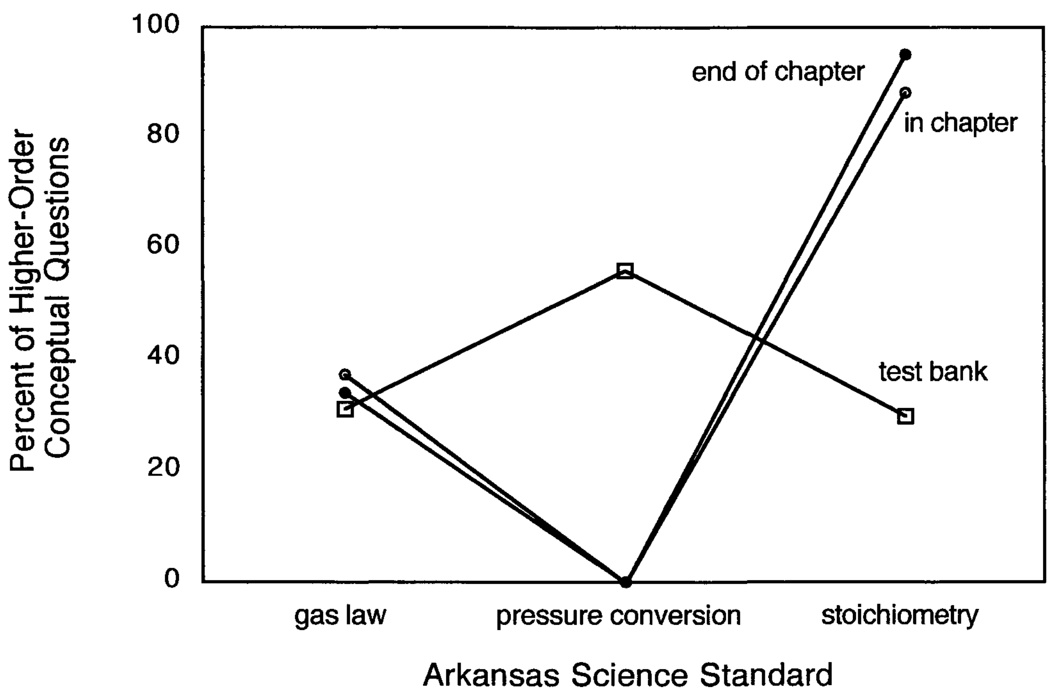

Figure 4a. Interaction plot for BL × BT × QP × ST association for high school textbooks.

Looking at Figure 4b, there seem to be three data points that most dramatically affect the non-parallel nature of these six lines, and we will focus our discussion on those points. In Figure 4a, the 'Higher-order/High school/Test-bank/Pressure conversion' point appears to be too high and the 'Higher-order/High school/Test bank/Stoichiometry' point appears to be too low. In Figure 4b, the 'Higher-order/College/End-of-chapter/Pressure conversion' appears to be too high. In the high school test banks, there appears to be more higher-order pressure conversion and fewer higher-order stoichiometry questions

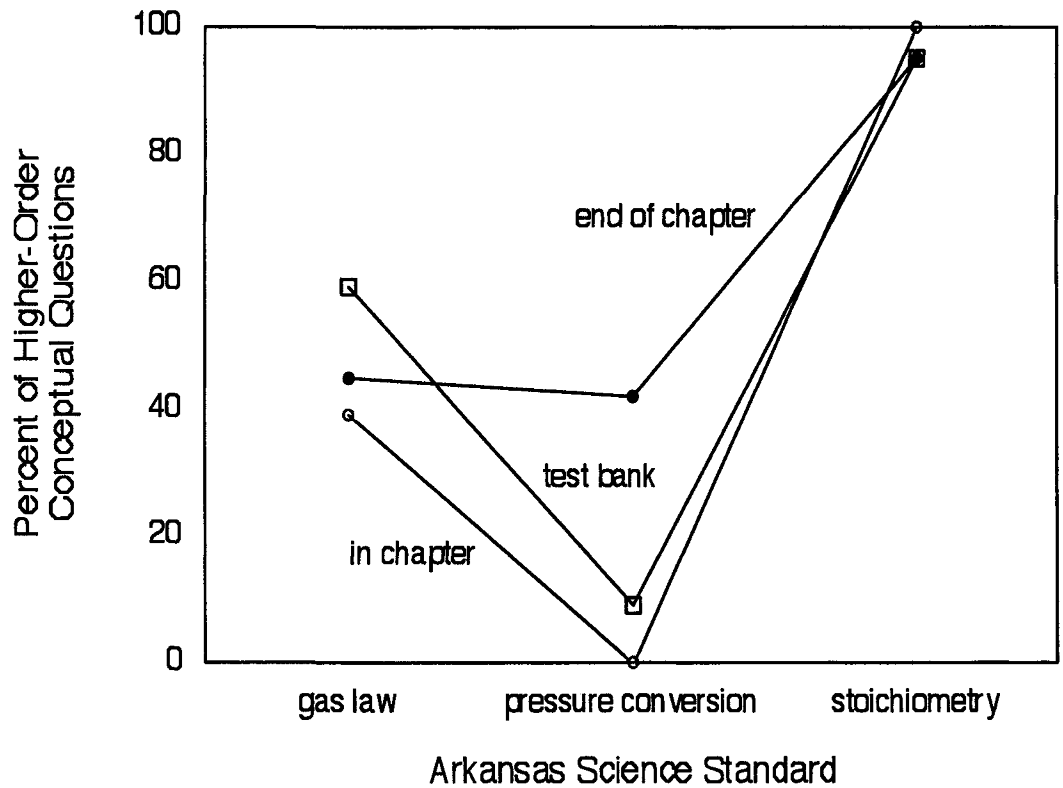

Figure 4b. Interaction plot for BL × BT × QP × ST association for college textbooks.

than predicted. This discrepancy could be due to test-bank authors attempting to provide instructors with a balance of higher- and lower-order questions on each topic (already described in the BL × QP × ST three-way association). The larger proportion of higher-order pressure conversion questions at the end of the chapters in the college textbooks could be explained by the fact that college textbook authors decided to place higher-order pressure conversion questions at the end of the chapters so that students could practice these more difficult questions on their own to better prepare themselves for difficult questions that could appear on their college examinations. Based on the six lines in the interaction plot in Figure 4, it appears that the distribution of higher- and lower-order questions are much different for the high school test banks compared to the other five sections.

Conclusions

In this study, we compared the distribution of mathematical questions appearing in the gas law chapters of four high school and four college chemistry textbooks based on five variables—Book Type (high school or college), Bloom's Taxonomy (higher- or lower-order), Question Format (multiple-choice or problem), Question Placement (in-chapter, end-of-chapter, or test bank), and Arkansas Science Framework Standards (gas law, pressure conversion, or stoichiometry). The Question Placement variable seemed to have the greatest impact on the distribution of questions, appearing as part of seven of the eleven significant associations identified in this study.

Differences in in-chapter, end-of-chapter, and test-bank questions. This study showed that the distribution of questions in the gas law chapters, at the end of the chapters, and in the test banks were very different. There were more questions appearing at the end of the chapters and in the test banks than in the chapters. The high school textbooks had a higher proportion of their questions in the chapters, while the college textbooks had a higher proportion of their questions at the end of the chapters. There was a higher proportion of problem questions in the chapters and at the end of the chapters and there was a higher proportion of multiple-choice questions in the test banks—this trend was more extreme for the college textbooks than the high school textbooks.

The goals of questions in these three places are different, and this could explain the differences in question distribution. In-chapter questions are used to introduce students to the methods used to solve chemistry problems. Because these worked-out examples take up more space, it makes sense that textbooks would have fewer in-chapter questions compared to the end-of-chapter and test-bank questions. High school textbooks would have more of these questions because high school students are often learning these chemistry topics for the first time and would need more assistance from the book. Since the goal of these questions is to show how to perform chemistry calculations, it makes sense that they would favor problem over multiple-choice format.

End-of-chapter questions allow students to practice their problem-solving skills and to prepare for course examinations. College chemistry textbooks may have more end-of-chapter questions because college chemistry instructors value students' autonomy and responsibility in monitoring their own learning. So, college books would provide several examples of the same questions at the end of the chapters for students to practice on their own. The goals of end-of-chapter questions, however, do not explain why textbooks would provide only problem questions (no multiple-choice). This bias in format may impair students' abilities to prepare for course examinations especially if their instructor uses multiple-choice questions on their examinations. The lack of multiple-choice questions at the end of the chapters may also hinder students' performance on standardized assessments (like NCLB assessments, ACS examinations, or other standardized test like SAT, ACT, MCAT, GRE, etc.)

Test-bank questions are typically used by chemistry instructors to construct their examinations. Because instructors would benefit from having several examples of the same question types to choose for their examinations and because test bank questions do not take up a lot of space (and usually appear in a separate book), it is not surprising that test banks would have more questions than the in-chapter section of the book. As with end-of-chapter questions the goals of test-bank questions do not adequately explain why textbooks use mostly multiple-choice format for these questions. The lack of problem questions in test banks limits their usefulness for teachers who do not want to use exclusively multiple-choice questions. Worse yet, test banks can also encourage course assessments to be solely multiple-choice—if instructors want to use the test bank to write their examination, their test will have to be in the multiple-choice format.

Comparison of the two studies. Although this study focused on the mathematical (calculation) questions and the previous study *(25)* focused on the conceptual questions in the gas law chapters of the same textbooks, we saw many of same significant interactions for the distribution of these types of questions. We believe that the significant associations appearing in both studies may represent larger trends in the distribution of questions that would be applicable to other chapters in these textbooks and may tell us something about the current state of teaching and learning general chemistry as it relates to using textbooks. The following associations were found to be significant in both studies—QF, QP, BT × QP, QF × QP, and BT × QP × QP. Although both studies showed significant ST association, it is difficult to compare these results because each study focused on different aspects of the Arkansas Science standards.

The significant QF associations in both studies showed the number of multiple-choice questions was lower than the number of short-answer (conceptual) or problem (mathematical) questions. This association either seems to suggest that textbook authors value multiple-choice questions less than the other two formats or that writing multiple-choice questions is too difficult or time-consuming. As instructors, we believe that the first reason is probably more important. The use of short-answer and calculation questions provides students with opportunities to express their ideas in their own words. This use tends to minimize the effects of random guessing with respect to multiple-choice questions. However, if instructors (and textbook authors) favor short-answer and calculation questions over multiple-choice questions, then why have so many important tests (like ACS examinations, NCLB assessments, SAT, ACT, MCAT, GRE, etc.) with major implications for students and schools alike, chosen multiple-choice format?

Both studies also identified significant QP associations, showing that there were more end-of-chapter and test-bank questions than in-chapter questions. We believe that there are fewer in-chapter questions in these textbooks because each in-chapter question involves a detailed explanation of how the question should be answered, including sample calculations. Since these questions take up more space, textbook authors tend to provide only one worked-out example for each calculation. Textbook authors tend to provide more end-of-chapter questions to give students more opportunities to practice questions that might appear on their examinations and to give instructors more choices of questions to assign for homework. Providing more test-bank questions also gives instructors more choices of questions to use for their examinations, which can be very important for instructors who have multiple sections of students each semester. It is important to note (for all of these associations) that we are not saying that it is necessarily wrong or bad to have a different proportion of questions in the subcategories of any variable, especially if there are pedagogical reasons for these differences.

For the significant BT × QP associations, both studies found that college textbooks had fewer of their questions within the chapters and more of their questions at the end of the chapters than high school textbooks. Since high school textbooks are being used by students who have probably not studied chemistry before, it is not surprising that the textbook authors would put more questions within the chapters where they could show students how to solve them. College students, who have probably studied chemistry in high school, would not need as many worked-out examples to learn material they have already seen. Since college instructors want to encourage their students to take an active role in monitoring their own learning, it makes sense that these textbooks would provide many end-of-chapter questions that students could practice on their own to prepare for their examinations.

The significant QF × QP association in both studies showed that the in-chapters and end-of-chapter questions consisted of very few multiple-choice questions but the test banks were mostly multiple-choice format. Based on our analysis of the questions, we cannot see a reason why textbooks should have so few multiple-choice questions or why test banks should contain predominately multiple-choice questions. If the goal of end-of-chapter questions is to prepare students for their course examinations (or future standardized tests) that use the multiple choice format, then it does not make sense that these textbooks would contain no multiple-choice end-of-chapter questions. Similarly, if the goal of test bank questions is to provide instructors with questions that could be used as part of their examinations, it is odd that test banks would contain mostly multiple-choice questions but few short answer or problem questions. The significant BT × QF × QP associations found in both studies showed that the trend of having very few multiple-choice questions at the end of the chapters and mostly multiple-choice questions in the text banks was more extreme for college textbooks than for high school textbooks.

We would ask textbooks authors to think about their assumptions (conscious or otherwise) governing the placement of questions in their textbooks. This is especially important with respect to the QF × QP association identified in this study, which seems arbitrary. We believe that students and instructors would benefit from having more multiple-choice questions at the end of the chapters and more short answer or problem questions in the test banks. We would also urge chemistry instructors to pay attention to the results of this study. For example, if their students are expected to take tests in the multiple-choice format (NCLB assessments or college-entrance examinations), then instructors should provide examples of multiple-choice chemistry problems in class and in the homework to compensate for the lack of multiple-choice questions in and at the end of the textbooks chapters.

These two studies started by asking how the distribution of questions in high school and college textbooks is different, with the idea that high school teachers might want to know which of these books to use in an Advanced Placement chemistry course. These studies showed that high school and college textbooks are very different with respect to their distribution of questions for the gas law chapters. We believe that the results of these two papers can assist AP chemistry teacher in trying to decide what type of textbook to use for their course.

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CHAPTER 4. ^{35}Cl NQR SPECTRA OF GROUP 1 AND SILVER DICHLOROMETHANESULFONATES

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Abstract

The dichloromethanesulfonates of silver and other +1-charged cations, $M^+(Cl_2CHSO_3^-)$ (M = Ag, Tl, Li, Na, K, Rb, Cs) were synthesized and studied by ^{35}Cl NQR. Dichloromethanesulfonic acid was prepared by the methanolysis of dichloromethanesulfonyl chloride, and was then neutralized with the carbonates of the +1-charged cations to produce the corresponding dichloromethanesulfonate salt. This NQR study completed the investigation of the chloroacetates and chloromethanesulfonates of silver, $Ag^+(Cl_xCH_{3-x}SO_3^-)$ and $Ag^+(Cl_xCH_{3-x}CO_2^-)$, and suggests (1) that the ability of organochlorine atoms to coordinate to silver decreases as the number of electron-withdrawing groups (Cl, SO_3^-, CO_2^-) attached to the carbon atom increases; (2) that the unusually large NQR spectral width found among $M^+(Cl_2CHCO_2^-)$ salts is not present among $M^+(Cl_2CHSO_3^-)$ salts, and therefore is not generally characteristic of the dichloromethyl group in salts.

Introduction

In recent years it has been shown that chlorocarbons such as CH_2Cl_2 can coordinate to soft-acid metal ions such as Ag^+ *(1)*. However, similar complexes of more highly chlorinated alkanes ($CHCl_3$, CCl_4) have not been found. This could be due to the electron-withdrawing chlorine atoms reducing the electron-donor properties of the organochlorine atom excessively. Including the chloroalkane in a sulfonate salt assures that it will be in a solid lattice with the Ag^+ ion, where has an opportunity to coordinate with Ag^+. Silver (I) monochloromethanesulfonate, $Ag^+(ClCH_2SO_3^-)$, was synthesized earlier and was shown by X-ray crystallography and ^{35}Cl NQR (nuclear quadrupole resonance) spectroscopy to have Ag-Cl coordination (organochlorine coordination to Ag^+ produces a relatively large shift of ^{35}Cl NQR frequencies to lower values) *(2)*. Silver (I) trichloromethanesulfonate $Ag^+(Cl_3CSO_3^-)$ *(3)* was also synthesized; NQR indicated that it did not have such coordination *(3)*. Although silver dichloromethanesulfonate, $Ag^+(Cl_2CHSO_3^-)$, was synthesized by Senning *(4)*, it was not structurally characterized; like $CHCl_3$, it contains three strongly electron-withdrawing groups, which may hinder coordination of the organochlorines to the silver ion. One goal of this work was to characterize this salt and study it by NQR to determine whether this coordination occurs.

A second purpose of this work is to shed light on the peculiar NQR spectral properties of dichloroacetates, $M^+(Cl_2CHCO_2^-)$. The ^{35}Cl NQR spectra of metal dichloroacetates contrast to the spectra of chloroacetates, trichloroacetates, chloromethanesulfonates, and trichloromethanesulfonates in two major respects: (1) the signals are much more difficult to detect; (2) when found, the NQR signals are sometimes very broad and spread over an extraordinarily large frequency range (spectral width) *(5-*

7). We entertained a hypothesis that these properties might be due to possible enhanced (acidic) hydrogen-bonding properties of the dichloromethyl hydrogen when the electron-withdrawing carboxylate (CO_2^-) group is attached. If this is so, then replacing carboxylate with the even more electron-withdrawing sulfonate (SO_3^-) group should enhance the NQR spectral width. Thus we have also prepared dichloromethanesulfonates (Figure 1a) of other +1-charged cations to compare with the corresponding dichloroacetates by NQR spectroscopy.

Although dichloromethanesulfonyl chloride, Cl_2CHSO_2Cl (Figure 1b), is commercially available from Lancaster Synthesis, the sulfonic acid, Cl_2CHSO_3H, has very infrequently been prepared. Backer *(8)* prepared the barium salt of the acid by heating barium sulfoacetate, concentrated hydrochloric acid, water, and barium chlorate.

$$Ba^{2+}(O_3SCH_2CO_2^-)_2 + 3\ Cl_2 \rightarrow Ba^{2+}(O_3SCHCl_2^-)_2 + 2\ HCl + 2\ CO_2 \qquad (1)$$

The product was treated with sulfuric acid to produce the sulfonic acid. Later, Senning, et al. *(4)* prepared chloromethanesulfonic acids by the solvolysis of the corresponding sulfonyl chloride with methanol.

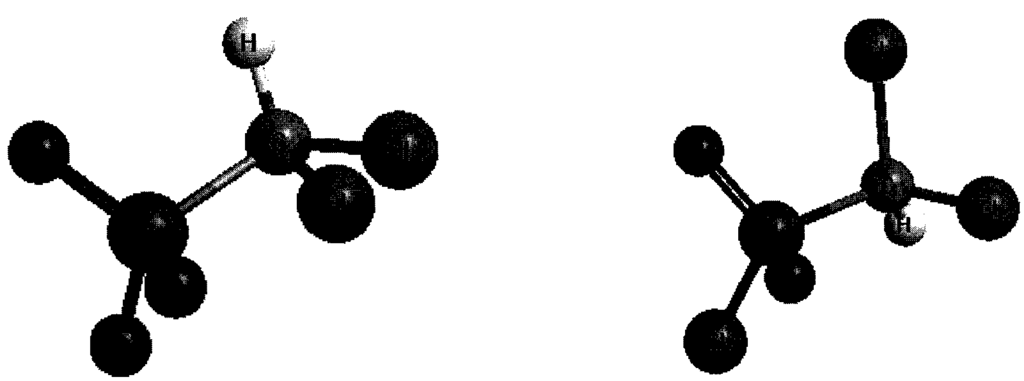


Figure 1. (a) Dichloromethanesulfonate ion (at left); (b) Dichloromethanesulfonyl chloride.

$ClCH_2SO_2Cl + CH_3OH \rightarrow ClCH_2SO_3H + CH_3Cl$ (2)

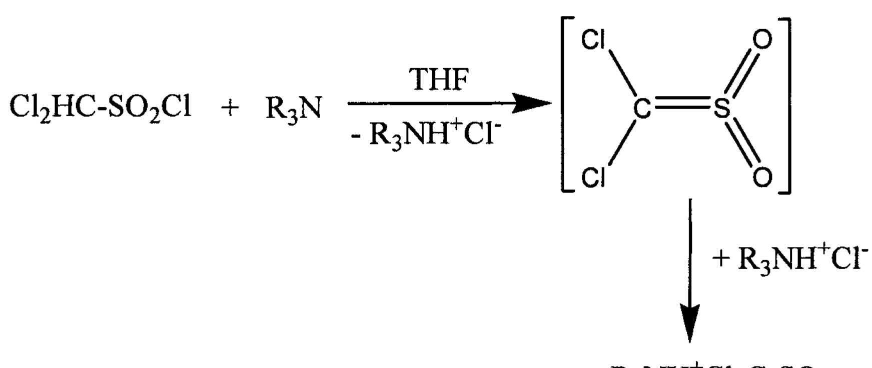
Wulfsberg, et al. *(2)* prepared monochloromethanesulfonates by the reaction of chloromethanesulfonyl chloride, $ClCH_2SO_2Cl$, with Group I metal carbonates in methanol.

$ClCH_2SO_2Cl + Tl_2CO_3 \rightarrow TlCl + Tl^+(ClCH_2SO_3^-) + CO_2$ (3)

Trichloromethanesulfonates were prepared using aqueous metal hydroxides and were easily separated from the metal chloride by recrystallization *(3)*.

$Cl_3CSO_2Cl(s) + 2\ CsOH(aq) \rightarrow CsCl(aq) + Cs^+Cl_3CSO_3^-(aq) + H_2O$ (4)

However, work by Hanefeld et al *(7)* indicated that the reaction of dichloromethanesulfonyl chloride with stronger bases proceeds anomalously with reverse umpolung (charge reversion).



(5)

Hence, we sought a synthesis that avoided the use of strong bases.

Experimental

NMR and NQR characterization. ^{35}Cl NQR spectra were obtained at 77K using a Decca NQR-1 continuous-wave spectrometer. ^1H and ^{13}C NMR spectra were obtained with a 300-MHz JEOL ECX pulse-FT NQR spectrometer. The starting material,

Cl_2CHSO_2Cl, gave a single ^1H peak in $CDCl_3$ at 6.56 ppm and a single ^{13}C NMR peak at 83.7 ppm. All salts gave single peaks in D_2O: ^1H at 6.45 ± 0.02 ppm; ^{13}C at 76.2 ± 0.01 ppm. Elemental analysis was carried out by Galbraith Laboratories.

Dichloromethanesulfonic acid. Dichloromethanesulfonyl chloride (2.00 g, 10.9 mmol) in 100 mL methanol (a 0.1.09 M solution) was refluxed in a 250 mL round bottom flask for 24 hours with constant stirring. After cooling to room temperature, a sample of the very acidic solution was titrated with standardized NaOH (0.0469 M) to a phenolphthalein endpoint. The calculated molarity of the hydrogen ion in the solution was 0.0.132 M.

Cesium dichloromethanesulfonate. In a 100 mL round bottom flask, 38.0 mL of the Cl_2CHSO_3H/HCl solution in methanol (5.01 mmol acid) were neutralized with 0.82 g (2.5 mmol) of Cs_2CO_3. The solvent was reduced to a small volume by rotary evaporation and then cooled in the refrigerator for 24 hours. The crystals (1.01 g, 61% yield) were recovered by vacuum filtration, after washing with a small volume of methanol. Elemental analysis results were 4.12% C, <0.5% H, and 23.44% Cl as compared to the calculated values for $Cs^+Cl_2CHSO_3^-$ of 4.05% C, 0.34% H, and 23.88% Cl.

Sodium dichloromethanesulfonate. In a 100 mL round bottom flask, 50.0 mL of the Cl_2CHSO_3H/HCl solution in methanol (6.60 mmol acid) was neutralized with 0.37 g (3.33 mmol) of Na_2CO_3. The solvent was reduced to a small volume by rotary evaporation and then cooled in a refrigerator for 24 hours. The crystals were washed with methanol, but dissolved readily. Toluene (5.0 mL) was added and the volume was reduced by rotary evaporation; the solution was placed in the refrigerator. The crystals

(0.73 g, 72% yield) of $Na^+Cl_2CHSO_3^-$ were recovered after washings with 10 mL toluene and 10 mL pentane.

Thallium (I) dichloromethanesulfonate. Tl_2CO_3 (3.91 g, 8.34 mmol), dichloromethanesulfonyl chloride (1.43 g, 8.34 mmol), and 15 mL of methanol were refluxed in a 250 mL round bottom flask for 24 hours. The precipitate of TlCl was removed by vacuum filtration. The filtrate was reduced in volume by rotary evaporation and cooled to give $Tl^+Cl_2CHSO_3^-$ (2.71 g, 88% yield).

Silver dichloromethanesulfate. Working under red light, dichloromethanesulfonyl chloride (0.92 g, 5.0 mmol), a large excess of Ag_2O (2.83 g, 24.4 mmol) and 100 mL of methanol were combined in a 250 mL round bottom flask. The flask was covered with aluminum foil to prevent light contamination. The solution was refluxed for 24 hours with constant stirring. The solids, AgCl and excess Ag_2O, were filtered and washed with small portions of methanol. The solvent was removed from the filtrate by rotary evaporation to give 0.96 g (4.14 mmol, 71% yield) of $Ag^+Cl_2CHSO_3^-$.

Results and Discussion

Syntheses. We prepared dichloromethanesulfonic acid by refluxing dichloromethanesulfonyl chloride in methanol and refluxing at 50 – 60°C for 24 hours. Titration of the resulting acidic solution indicated that the reaction with non-dried methanol produced both hydrochloric acid and dichloromethanesulfonic acid.

$$Cl_2CHSO_2Cl + CH_3OH \rightarrow Cl_2CHSO_3H + CH_3Cl \quad (6)$$

$$Cl_2CHSO_2Cl + H_2O \rightarrow Cl_2CHSO_3H + HCl \quad (7)$$

The titration indicated a fairly low yield of HCl and no difficulty was experienced after neutralizing with metal carbonate in separating the dichloromethanesulfonate salts from the more soluble chloride salts.

$$Cl_2CHSO_3H + HCl + Cs_2CO_3 \rightarrow Cl_2CHSO_3^-Cs^+ + Cs^+Cl^- + CO_2 + H_2O \quad (8)$$

Dichloromethanesulfonates of Cs, Rb, and K were prepared in this manner, and were rinsed free of chlorides with methanol The sodium and lithium salts were soluble in the methanol rinse, so were recrystallized from methanol/toluene and washed with toluene and pentane.

Thallium (I) and silver (I) dichloromethanesulfonates could be prepared by direct reaction of Cl_2CHSO_2Cl with Tl_2CO_3 or Ag_2O in methanol upon refluxing for 24 hours. The insoluble TlCl and AgCl were filtered off and the desired salts were obtained by rotary evaporation of the methanol.

$$Cl_2CHSO_2Cl + Ag_2O \rightarrow AgCl + Ag^+Cl_2CHSO_3^- \quad (9)$$

As both Tl_2CO_3 and Ag_2O are insoluble in alcohol, this reaction evidently did not produce basic enough condition to lead to the reverse umpolung reaction (5) noted by Hanefield et al. *(7)*.

NQR Spectra. The ^{35}Cl NQR spectra of the salts at 77K is given in Table 1. With the exception of the silver salt, the spectral widths of the dichloromethanesulfonates do not exceed 1.0 MHz, and thus do not exceed the normal (small) spectral width ($\Delta\nu$ between the highest and the lowest NQR frequency at 77K) due to crystallographic inequivalence of chlorines of less than about 0.8 MHz for molecular compounds and less than perhaps 1.5 MHz in ionic chloroacetates *(3)*. This is in sharp contrast to the large spectral widths of 2.075 MHz found in $Na^+(Cl_2CHCO_2^-)$, 3.135 MHz found in

$(CH_3)_4N^+(Cl_2CHCO_2^-)$, and 2.130 MHz found in $Ba^{2+}(Cl_2CHCO_2^-)_2$ *(5)*. Thus the large spectral widths appears not to be a function of the dichloromethyl group itself, but is found only (so far) in dichloroacetates. This appears to refute our early hypothesis concerning enhanced hydrogen-bonding effects of the dichloromethyl hydrogen in salts with electron-withdrawing groups.

As shown in Figure 2, the average NQR frequencies of the dichloromethanesulfonates are inversely related to the cation radius, as was previously found for all other chloroacetates and chloromethanesulfonates *(3)*. For a given cation, the NQR frequency of the three types of chloroacetate salts increases with increasing chlorine substitution in the chloroacetate ion; the same holds true for all three types of chloromethanesulfonate. For a given cation and constant chlorine content, the NQR frequency of the chloromethanesulfonate is higher than the frequency of the chloroacetate, in line with the greater electron-withdrawing effect of the sulfonate group as compared to the carboxylate group.

Among silver salts, the spectral widths are greatest in silver dichloroacetate (2.898 MHz *(10)*), and decrease through the series silver dichloromethanesulfonate (1.926 MHz, Table 1), silver trichloroacetate (1.834 MHz *(3)*), while in silver trichloromethanesulfonate monohydrate the spectral width of 0.710 MHz does not suggest any coordination of organochlorines to silver *(3)*. In silver chloroacetate and silver chloromethanesulfonate, all chlorines are coordinated *(3, 11)* so no unusual spectral width is generated. Silver chloroacetate is a covalent dimer, $(ClCH_2COO)_2Ag_2$, with an average ^{35}Cl NQR frequency of 33.671 MHz, which falls 2.59 MHz below the average frequency for the non-coordinated chlorines in the dimeric $(ClCH_2COO)_4Cu_2$ *(4)*; the

2.59 MHz may therefore approximate to the unavailable spectral width. If this may legitimately be compared with the spectral widths of the four silver di- and trichloro- salts, then it may be seen that, with the exception of silver dichloroacetate, the spectral width decreases with the increase in the number of the chlorines, and for constant number of chlorines, the effectiveness of the electron-withdrawing groups. This then suggests (but does not prove) that the electron-donating ability decreases in the same series, but perhaps does not vanish until the last member of the series, silver trichloromethanesulfonate.

Compound	NQR Frequencies (MHz)		Average	Spectral Width
Cl_2CHSO_3Ag	39.018 (6)	37.192 (3)	38.110	1.926
Cl_2CHSO_3Tl	38.049 (2)	37.784 (3)	37.514	1.013
	37.562 (3)	37.435 (3)		
	37.218 (2.5)	37.036 (2)		
Cl_2CHSO_3Cs	37.886 (7)	37.673 (6)	37.444	0.886
	37.218 (5)	37.000 (5)		
Cl_2CHSO_3Rb	38.186 (2)	37.821 (3)	37.712	0.825
	37.479 (3)	37.361 (3)		
Cl_2CHSO_3K	38.175 (2.5)	37.750 (2.5)	37.962	0.425
Cl_2CHSO_3Na	38.392 (3)	38.265 (3)	38.182	0.453
	38.131 (3)	37.939 (3)		
Cl_2CHSO_3Li	39.056 (8)	38.817 (10)	38.936	0.239

[a] Signal-to-noise ratios are given in parentheses.

Table 1. 77K ^{35}Cl NQR Frequencies of Ionic Dichloromethanesulfonates (MHz)[a].

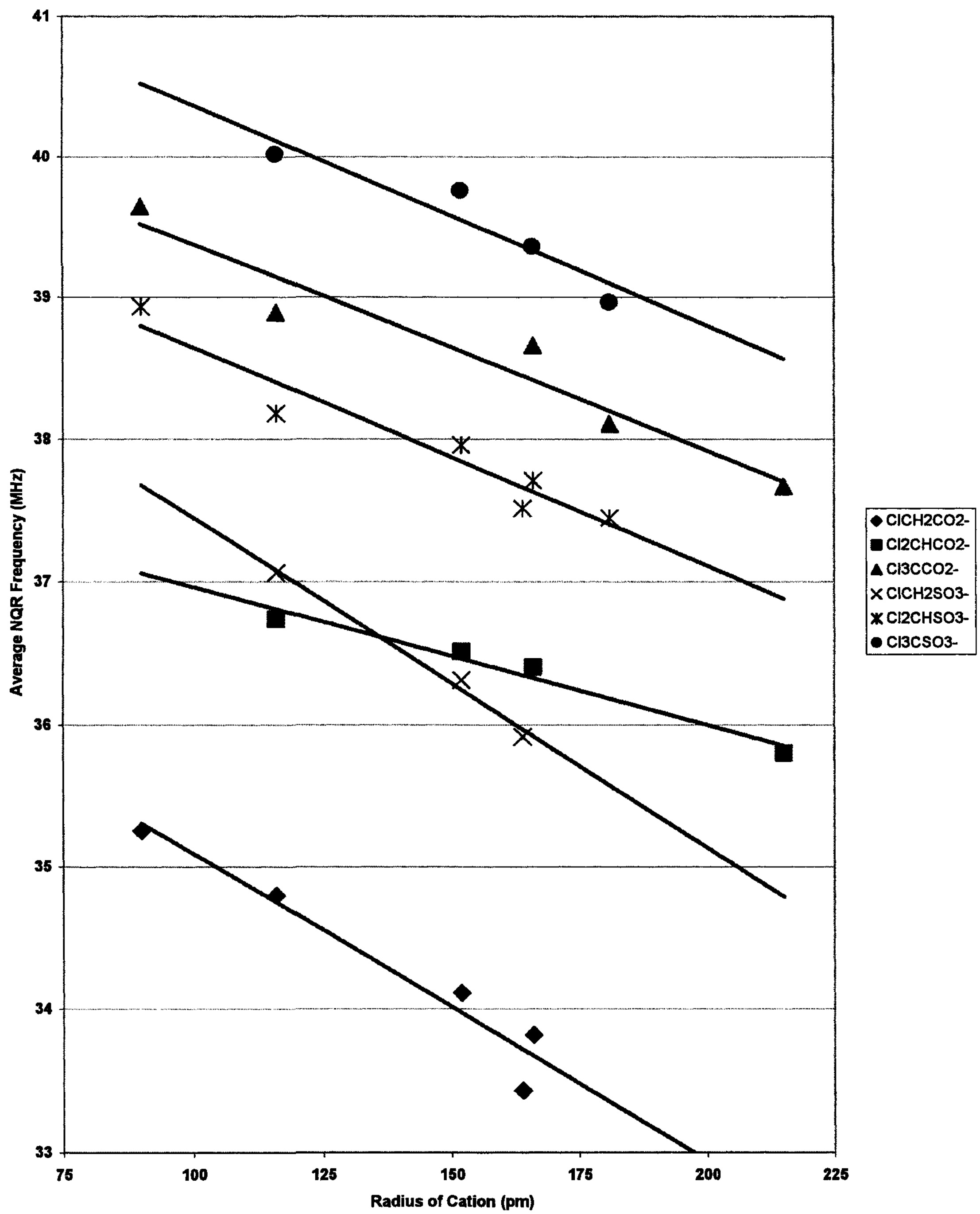


Figure 2. Average ^{35}Cl NQR Frequencies (MHz, at 77K) of Group 1 and Tl^{+} Salts of Chloroacetate and Chloromethanesulfonate Anions. (Silver salts excluded.)

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CHAPTER 5. CONCLUSION

All six variables (Bloom's Taxonomy, Book Type, Question Format, Question Placement, Representation, and Arkansas Science Standards) appeared in the significant associations identified in this study. Three of these variables (Book Type, Question Placement, and Arkansas Science Standard) appeared most often in the significant associations and had the biggest impact on the question distributions in the eight chemistry textbooks.

The distribution of questions in the high school and college textbooks are very different. The high school textbooks had 43% more conceptual questions than the college textbooks while the college textbooks had 62% more mathematical questions than the high school textbooks. The high school textbooks also had more of their questions placed within the chapters while the college textbooks had more of their questions placed at the end of the chapters. The high school textbooks had more multiple-choice questions at the end of the chapters and more short-answer and problem questions in the test banks than the college textbooks. Most of the differences between the distribution of questions in high school and college textbooks could be explained by the fact that college textbooks are generally geared toward students who have some background in chemistry, while high school textbooks are generally geared toward students taking chemistry for the first time.

The textbooks also had very different distributions of questions within the chapters, at the end of the chapters, and in the test banks. There were more questions appearing at the end of the chapters and in the test banks compared to the number of questions within the chapters. Also, there were more in-chapter questions in the high school textbooks and more end-of-chapter questions in the college textbooks. A major finding of this study was that these textbooks had very few multiple-choice questions within and at the end of the chapters but had mostly multiple-choice questions in the test banks. This trend was also found to be more extreme for the college textbooks compared to the high school textbooks. This difference in question distribution could be explained by the different goals of the in-chapter questions (intended to introduce new concepts to the student), the end-of-chapter questions (intended to give the student opportunities to practice their problem-solving skills and prepare them for course examinations), and the test-bank questions (intended to give the chemistry instructor examples of questions to use for his or her examinations).

The difference in question distributions with respect to the Arkansas science standards was most noticeable in the study of the mathematical questions. Most (72%) of the mathematical questions related to the gas law standard, while the rest of the questions related to pressure conversion (13%) and the stoichiometry (11%) standards. Although the gas law questions were half lower-order and half higher-order, the pressure conversion questions were mostly lower-order and the stoichiometry questions were mostly higher-order. These differences could be explained by the different concepts described by the three standards. The reason there was a large number of gas law questions is that this standard relates to several topics discussed covered in multiple sections in the textbooks while the pressure conversion and stoichiometry questions each appear in a single section of the textbooks. Most of the pressure conversion calculations are lower-order because these calculations usually involve a single step to convert from one pressure unit to another (for example, atm to Pa). On the other hand, most of the stoichiometry calculations are higher-order because these calculations require more than one step (calculating the number of moles of a gas present, and converting the number of moles of the gas to the mass of another chemical).

It is certainly possible to write chemistry textbooks so that there would be no associations among any of the variables (i.e., the distribution of question types would be completely homogeneous). However, this may not be optimal. For example, it may not make sense to write more symbolic questions about the conceptual standard (kinetic molecular theory) or more particulate questions about the mathematical standards (gas laws and stoichiometry calculations). It also would not make sense to write high school and college textbooks identically if the populations of students for which they are intended are not identical. Textbook authors need to think about the assumptions (conscious or otherwise) that guide their placement of questions in the textbooks. Most significantly, I would urge textbook and test-bank authors to consider placing more multiple-choice questions at the end of the chapters and more short-answer questions in the test banks. This is especially important if the student is expected to take formal assessments (No Child Left Behind assessments, American Chemical Society examinations, SAT, ACT, MCAT, GRE, etc.) involving multiple choice questions.

What does this study have to say to the high school chemistry teacher trying to decide whether to use a high school or college chemistry textbook for his or her Advanced Placement course (the original question that lead me to perform this study)? This study showed that the high school and college chemistry textbooks are very different with respect to the distribution of questions within their gas law chapters. Still, this study has its limitations. For example, there is no guarantee that these differences would still be found if I chose to analyze eight different chemistry textbooks. The differences in question distribution might also be very different if I had chosen to analyze another chapter within these textbooks. In order to choose the proper chemistry textbook for his or her class, an AP chemistry teacher should analyze the goals of this class and the characteristics and needs of their students in this class before choosing a textbook. This study pointed out some of the differences in the distribution questions asked in high school and college textbooks but there are undoubtedly other. Finally, this study identified some deficiencies in the distribution of the questions in high school and college textbooks (like the lack of multiple-choice questions at the end of the chapters and the lack of short-answer and problem questions in the test banks). Chemistry instructors need to recognize these deficiencies and, when necessary, change their instruction and/or their assessment activities to address or correct these deficiencies.

Even though this study was limited to the gas law chapters of the chemistry textbooks, there is no reason the process of categorizing questions could not be extended to other concepts found in chemistry textbooks. My original intention for this study was to analyze three chapters—the stoichiometry chapters (which are predominantly mathematical in nature), the gas law chapters (which tend to have an even mix of mathematical and conceptual topics), and the molecular geometry chapters (which are predominantly conceptual in nature). It would be interesting to see if the distribution of questions is affected by the conceptual/mathematical emphasis of the individual chapters. This could be analyzed in a future study.

The general properties of gases and the gas laws are discussed in other science disciplines in addition to general chemistry. The analysis used in this study could be extended to the gas law chapters in these other science disciplines (physics and physical science). Presumably, they would have slightly different Arkansas Science Framework Standards and these differences could be useful in explaining any differences in question distribution that might be identified. It might also be interesting to perform an analysis of the questions in the gas law chapters using the science framework standards from another state, although it is unlikely that the standards from any other state would be largely different from the standard used in Arkansas. Most of the variables used in this study (with the notable exception of the chemical Representation variable) are largely independent of the area of study, and this type of question analysis could be extended to the other (science or non-science) disciplines, such as history or mathematics.