

ANALYSIS OF TURKISH HIGH SCHOOL CHEMISTRY  
TEXTBOOKS AND TEACHER-GENERATED QUESTIONS  
ABOUT GAS LAWS

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**ABSTRACT.** This study presents the results of an analysis of high school chemistry textbooks and teacher-generated questions about gas laws. The materials that were analyzed consisted of 456 questions about gas laws found in seven grade 10 chemistry textbooks and 264 teacher-generated examination questions prepared by seven chemistry teachers from three schools. These questions were classified into three categories (recall, algorithmic, and conceptual); the conceptual questions (ConQ) were further classified into six subcategories (particulate, demonstration, tiered, laboratory, analogy, and series completion) using the descriptions provided on the Conceptual Questions and Challenge Problems website. The findings indicate that most of the textbook questions were algorithmic and that these textbooks were less likely to facilitate or encourage student comprehension of the properties and behaviors of gases or gas law theories. Furthermore, most of the textbook questions do not enable students to develop conceptual understanding and gain higher-order cognitive skills. Although the findings imply that most of the teacher-generated questions were ConQ, the large majority were partially conceptual type questions. The major implication of this research is the need for teachers, textbook writers, and academics to consider question types when creating questions or analyzing chemistry questions at all educational levels.

**KEY WORDS:** conceptual understanding, gases, high school chemistry textbooks, problem solving

#### INTRODUCTION

The conceptual understanding and assessment of knowledge are essential issues in chemistry teaching and learning. Conceptual understanding requires students' in-depth understanding, connections among new and prior knowledge, and strong cognitive organization of knowledge (conceptual network). Conceptual understanding also involves the logical connections between fundamental chemical principles and the various representations that characterize chemical phenomena. However, student achievement in a chemistry course is usually assessed by the ability to solve algorithmic questions (AlgQ) (Nurrenbern & Pickering, 1987; Pickering, 1990; Zoller, Lubezky, Nakhleh, Tessier & Dori, 1995). Frequently, the problem solving assessed emphasizes rote application of

algorithms involving a mechanical computational procedure based on a simplified set of directions and may not fully reflect conceptual understanding of the chemistry involved in a complex problem (Herron, 1996; Schrader, 1987). Niaz & Robinson (1993) pointed out that formal operational reasoning is an important predictor of performance for chemistry problems requiring algorithmic strategies. Conversely, for chemistry problems requiring conceptual understanding, differences in performance are explained by various cognitive variables, such as information processing and formal operational reasoning (BouJaoude, Salloum & Abd-El-Khalick, 2004; Overton & Potter, 2008; Stamovlasis & Tsaparlis, 2005; Tsaparlis, 2005).

A major component of the current reform in science education is to develop students' higher-order cognitive skills (HOCS) of question asking, critical thinking, system thinking, decision making, and problem solving—as opposed to “traditional” algorithmic-based lower-order cognitive skills (LOCS; Zoller & Puskin, 2007). Furthermore, chemical education should develop students' capability to use these strategies so as to construct meaningful conceptual frameworks about the ideas and processes of chemistry. The type and level of problems and questions play critical roles in determining whether students develop HOCS, resulting in conceptual development. Solving algorithmic problems is neither compatible with most HOCS nor the production of conceptual understanding.

Traditionally, chemistry teaching is based on lectures and textbooks. The type of questions asked in both teacher-directed lessons and textbooks may influence the establishment and encouragement of HOCS and conceptual understanding. Unfortunately, in general, the questions asked in textbooks and examinations facilitate and reward the development of LOCS, such as algorithmic problem solving (Dávila & Talanquer, 2010; Lin, Cheng & Lawrenz, 2000; Niaz, 2000). Chiappetta, Fillman & Sethna (1991) found that high school chemistry textbooks not only de-emphasize science as a way of thinking but also do not stress the importance of how chemists historically developed ideas and experiments, established cause–effect relationships, and used self-examination of their thinking in the pursuit of knowledge.

The purpose of the present study was to investigate the quality of high school chemistry textbook and teacher-generated questions about gas laws and to discuss its implications for developing students' HOCS in high school chemistry courses. The study examined contemporary chemistry textbooks published in Turkey during the period 1998–2009.

*Problem Solving in Chemistry*

Gabel (1986) suggested that problem solving involves understanding the language of the problem, the determination of what is given in the problem and what is sought, an understanding of the science concepts involved in the problem and solution, and the ability to perform any mathematical operations involved in the problem. Hayes defined a problem as:

Whenever there is a gap between where you are now and where you want to be, and you don't know how to find a way to cross that gap, you have a problem (as cited in Bodner & Herron, 2003, p. 236).

Bodner (1991) suggested that this definition implies a fundamental difference between routine exercises and novel problems. The difference between an exercise and a problem is not a question of difficulty or complexity but rather one of familiarity. Bodner & McMillan (1986) suggested that, if you know what to do when you read a question, it is an exercise, not a problem.

Contemporary views of problem solving recognize the complexity of process and array of influential factors. Problem solving is “the process of moving from a situation in need of resolution to a solution overcoming any obstacles along the way” (Sternberg & Williams, 2002, p. 319). Some researchers have developed models in an attempt to understand or explain the problem-solving process (Polya and Wheatly, as cited in Bodner & Herron, 2003; Taasobshirazi & Glynn, 2009). Polya's problem-solving model consists of four stages: understanding the problem, devising a plan, carrying out the plan, and looking back. Bodner and Herron suggested that all problem-solving models have merit, but problem solving is a complex process that is affected by many variables and no single model captures its nuances.

Other researchers have studied the differences between the behavior of expert and novice problem solvers and found that experts use more conceptual approaches and that learner characteristics are important factors in the way students solve problems (Cartrette & Bodner, 2009; Heyworth, 1999; Stains & Talanquer, 2008). However, Camacho & Good (1989) concluded that problem-solving performance is a continuum—not a clear dichotomy between experts and novices. Bodner & Herron (2003) suggested that differences in behavior call attention to the growing repertoire of declarative and procedural knowledge a person can utilize in solving problems as expertise develops. Gabel & Bunce (1994) concluded

that the in-depth understanding of chemistry concepts required for solving problems involves more than knowledge of isolated concepts. Successful problem solvers use their conceptual understanding and make more connections between concepts. Such findings have encouraged researchers to examine problem solving and its relationship to students' conceptual understanding.

It has been shown that a significant percentage of chemistry students could easily use algorithmic equations to solve problems but had little understanding of the concepts described by those questions (BouJaoude et al., 2004; Chei, 2001; Nakhleh, 1993; Nakhleh & Mitchell, 1993; Nurrenbern & Pickering, 1987; Papaphotis & Tsaparlis, 2008; Tsaparlis & Zoller, 2003; Zoller, 1993; Zoller et al., 1995). Robinson (2003) suggested that the algorithms, which may seem helpful at first glance, actually promote an approach that hinders meaningful learning and true understanding. Since some students use these aids without understanding what they mean, they often solve problems successfully using memorized procedures but without mastery of relevant chemical concepts. Therefore, the type of problem questions used in classroom instruction and textbooks might initially encourage the use of algorithms and discount conceptual understanding.

### *Types of Questions*

Studies about problem solving and its relationship to students' conceptual understanding have categorized questions using different formats. Nurrenbern & Robinson (1998) indicated that student knowledge could be assessed by three broad categories of questions: recall, algorithmic, and conceptual. While recall questions (RecQ) require students to recall facts, equations, or explanations simply, AlgQ ask students to use information or processes in a familiar way. However, conceptual questions (ConQ) require students to synthesize an answer rather than simply recall the answer or activate an algorithm. They noted that many ConQ present a chemical situation that students have not experienced and ask them to justify a choice, predict what happens next, explain why and how something happens, link two or more areas or topics, recognize questions phrased in a novel way, and extract useful data from an excess of information.

Zoller et al. (1995) associated ConQ with HOCS and AlgQ with LOCS. LOCS questions require simple recall of information or a simple application of known theory or knowledge to familiar situations and context; HOCS questions include quantitative or qualitative, ill-defined ConQ unfamiliar to students that require much more than just the knowledge and application of known algorithms for their solutions

(Tsaparlis & Zoller, 2003). Several different formats of ConQ have been developed and made available by the Conceptual Questions and Challenge Problems (CQCP) website (Robinson & Nurrenbern, 2010). This resource provides six types (particulate, demonstration, tiered, laboratory, analogy, and series completion) of questions and problems that can be used in teaching and assessing conceptual understanding and problem solving in chemistry as well as a framework for categorizing classroom and textbook questions.

Particulate questions present a chemical situation at the atomic or molecular (microscopic) level, using circles or spheres of different sizes or colors to represent the particles, whereas demonstration questions are answered after observation of a demonstration, video, or simulation (macroscopic perspective). Tiered questions consist of a pair of questions; the first question presents a multiple-choice problem and the second question asks for a reason for the answer given in the first part. Laboratory questions use graphs, tables, and other data to predict and explain what happens in an experimental situation. Analogy questions require completing an analogy (e.g. A is to B as C is to D). The question stem contains the first part of the analogy (e.g. A is to B as ...) and an alternate that best completes the analogy is then selected (e.g. ... C is to D). Series completion questions require recognition of the common feature in a series followed by selection of an item that best completes the series.

### *Gas Laws and Problem Solving*

Gas laws are an important component of both high school and undergraduate chemistry curricula. Gas laws are related to the microscopic world of chemistry—providing the foundation for understanding the kinetic theory of gases—and its relation to the macroscopic world of chemistry—facilitating the comprehension of observable properties in gases. Teaching about gases and solving gas laws problems also involves the representation of conceptual ideas at the symbolic level. Johnstone (2000) suggested that one reason students have difficulty learning chemistry is that they do not understand the relationships between the macroscopic, submicroscopic, and symbolic levels. Dori & Hameiri (2003) emphasized that “one cannot correctly classify the problem without the deep understanding of the symbol, macro, micro, and process levels and the transformations among them” (p. 298). Gabel, Samuel & Hunn (1987) stated that the “ability to represent matter at the particulate level is important in explaining phenomena or chemical reactions, changes in state and the gas laws, stoichiometric relationships, and

solution chemistry” (p. 695). Furthermore, concerns about the gas laws contain both qualitative and quantitative properties of pressure–volume, pressure–temperature, and volume–temperature relationships and graphical representations. However, studies have indicated that, even after having been taught the particulate theory and the properties of gases, a significant number of high school students still believed that a gas has no weight (Lin et al., 2000; Stavy, 1988). Kautz, Heron, Loverude & McDermott (2005) found that, after instruction in introductory chemistry and physics as well as in more advanced courses, many university students were not able to properly interpret the macroscopic variables of pressure, temperature, and volume in an ideal gas.

Teacher-generated and textbook questions might be central to improving instruction, assessment, and learning. Lin et al. (2000) suggested that most assessment of gas laws conducted by chemistry teachers are algorithmic and emphasize mathematical calculations. Teacher-generated questions have been shown to affect the cognitive level of students’ thought processes (Bennett, Evans & Michel, 2003). Beall & Prescott (1994) found that students thought the calculational examination questions on gas laws were easier than the ConQ. Niaz (1994) pointed out that, despite the increasing consciousness among science educators of the difference between algorithmic and conceptual problems, more work was needed on the epistemological and psychological (cognitive variables) basis of this difference.

Niaz & Robinson (1992) explored the epistemological framework for understanding the behavior of gases and compared student performance on gas problems that require the algorithmic mode and conceptual gestalt. Problems requiring enumeration and manipulation of different variables (pressure, volume, etc.) of the Ideal Gas Law were characterized as the algorithmic mode, and problems requiring the use of the Ideal Gas Law (a hypothetico-deductive system requiring the understanding of a pattern within which data appear intelligible) were characterized as the conceptual gestalt. They found that student performance on problems requiring the two approaches was quite different in all items, except for one. They concluded that the ability to solve problems requiring the algorithmic mode is not the major factor in predicting success in solving problems based on conceptual gestalt. The results indicated that (a) performance on items requiring the algorithmic mode requires formal operational reasoning to a certain degree and (b) information-processing ability was an important predictor of success for the items requiring conceptual gestalt. Niaz (1994) found considerable differences in student performance on chemistry problems that require algorithmic or con-

ceptual understanding. He argued that the difference can be interpreted as a process of progressive transitions that facilitate different degrees of explanatory power to student conceptual understanding and that the relationship between algorithmic and conceptual problems is a continuum consisting of sequences of models that facilitate greater conceptual understanding.

The second important issue is the textbooks' presentation and questions provided for this topic; that is, do they present a framework to understand the epistemological difference between AlgQ and ConQ in gas laws. De Berg (1989) and De Berg & Treagust (1993) investigated the presentation of gas properties in Australian secondary school textbooks in terms of the qualitative–quantitative mode and gas law sequence. De Berg found that chemistry textbooks placed little emphasis on the qualitative understanding of gas properties and that only five of 80 exercises on the pressure–volume relationship inquired about the qualitative properties of gases. Lin et al. (2000) suggested that, since textbooks serve as a guide for science education, it is no surprise that algorithmic modes of problem solving are more common than conceptual modes.

Niaz (2000) developed a framework for examining the way in which chemistry textbooks describe the kinetic theory of gases based on the history and philosophy of science; the framework was developed by a rational reconstruction of Maxwell and Boltzmann's work. Another aspect of the framework was based on an analysis of first year university chemistry students' performance on gas problems that required the use of algorithms or conceptual understanding. First year chemistry textbooks ( $N = 22$ ) were evaluated using a framework consisting of six criteria. One criterion was to evaluate the degree to which the textbook explicitly recognizes the two modes of solving gas problems (i.e. algorithmic mode and conceptual understanding mode requiring a gestalt). The results revealed that none of the textbooks satisfactorily described or briefly mentioned the two modes and that most textbooks emphasized the ability to manipulate variables, such as mathematical transformation. However, some textbooks presented one or two problems that could be considered as conceptual or at least partially conceptual.

### *Scope of Study*

Gas laws are a regular part of the Turkish high school chemistry curriculum. Students' problem-solving performance and understanding will likely reflect the quality and type of questions used to present and



assess this topic; therefore, it is important to determine the quality of questions in textbooks and examinations. The textbook is an important teaching aid that conveys some of the information that students receive and influences how students perceive this subject (Chiappetta et al., 1991). The textbook and the questions it contains have a valuable role in improving students' conceptual understanding and HOCS. Furthermore, textbooks are one of the main factors that may affect the questions asked by the teachers both during the lessons and in the examinations; in this respect, they have an influence on students' understanding and reasoning skills.

Karamustafaoğlu, Sevim, Karamustafaoğlu & Çepni (2003) found that more than half of the questions in the Turkish university entrance examination (OSS) were of the HOCS type. Coştu (2007) investigated whether there were significant differences in Turkish high school students' performance and preferences among conceptual, algorithmic, and graphical questions. Contrary to previous research results (Nakhleh, 1993; Nakhleh & Mitchell, 1993; Nurrenbern & Pickering, 1987; Tsaparlis & Zoller, 2003; Zoller, 1993; Zoller et al., 1995), Coştu concluded that high school students performed significantly better on ConQ than on algorithmic or graphical questions. Moreover, most students demonstrated a strong preference for the ConQ. He suggested that the discrepancy between his findings and those of previous studies could be attributed to preparation for the OSS.

Although Coştu (2007) classified the questions in high school chemistry examinations into three categories (i.e. conceptual, algorithmic, and graphical), we believe that graphical questions can be considered a type of ConQ since they require students to interpret data and determine relationships between variables. When these categories were compared with ConQ categories provided on the CQCP website, we found that the graphical questions corresponded with the laboratory questions, requiring use of graphs, tables, and other data to predict and/or explain what happens in an experimental situation (Robinson & Nurrenbern, 2010). Furthermore, we found that some ConQ did not correspond fully to any of the ConQ types (i.e. particulate, demonstration, tiered, laboratory, analogy, and series completion). Examination of these questions revealed that they were partially conceptual type questions.

Given the potential problems of teaching chemistry using disproportionately large numbers of AlgQ and RecQ and not using different kinds of ConQ, it is important to analyze and rethink the ways in which high school chemistry textbook and teacher-generated questions are being used in the instruction and assessment of student knowledge about gas laws.



Although several studies have explored learning and teaching about gas laws, little is known about analyzing the various types of ConQ. The present study was guided by the following central research question: Are textbook authors and teachers selecting the types of questions that will enable students to develop HOCS? In order to explore this central question, this study examined three objectives:

1. To determine the distribution of textbook and teacher-generated examination questions according to whether they are recall, algorithmic, or conceptual type questions and to make comparisons among them.
2. To identify and compare which type of ConQ (particulate, demonstration, tiered, laboratory, analogy, or series completion) are available in high school chemistry textbooks and asked by teachers in examinations.
3. To evaluate whether the textbook and teacher-generated examination questions are associated.

#### METHOD

The research focus of this study was the curriculum used to teach a unit on gas laws in 10th-grade chemistry classrooms in Turkey. A nationwide curriculum is used for every course in elementary and secondary education. The research materials that were analyzed consisted of 456 questions about the gas laws found in seven 10th-grade chemistry textbooks published between 1998 and 2009 (Appendix 1) and 264 teacher-generated examination questions prepared by seven chemistry teachers randomly selected from three schools.

#### *Analysis Process*

A three-part analysis was conducted to establish a procedure and rubric to classify the textbook and teacher-generated questions. First, the main question categories (recall, algorithmic, and conceptual) and ConQ types (particulate, demonstration, tiered, laboratory, analogy, and series completion) were identified, using the descriptions provided on the CQCP website. Descriptions and example questions were developed for the categories by the authors. Most of these sample questions were selected from the pool of textbooks and teacher-generated questions. However, if there were no examples in a category, then a sample question was either taken from other published materials or developed. The rubric and examples were reviewed by a university professor with a Ph.D. in chemistry and many years of undergraduate and graduate teaching

experience. Second, all questions were analyzed and classified into one of the three main categories (Table 1). Third, a detailed analysis of all ConQ was conducted and these questions were classified into one of six types (Appendix 2, Part A).

The analysis of the ConQ revealed that some questions did not fit fully into the six CQCP categories. Further analysis of these partial conceptual questions (ParConQ) resulted in four additional subcategories: modified recall, modified calculation, qualitative answer with reason, and extra data (Appendix 2, Part B). These ParConQ did not require as much conceptual understanding as the ConQ.

### *Inter-rater and Intra-rater Reliability*

The inter-rater reliability was obtained by the two authors independently analyzing a random sample of 20 questions using the categorical descriptions. The authors first classified the sample recall, algorithmic, or conceptual groups. Then, they classified the ConQ into the six CQCP categories, compared and discussed their results, and determined that there was 90% agreement between their two findings (Gay & Airasion, 2000). Any questions that did not achieve identical results were discussed until a consensus was reached. Next, the second author analyzed and classified the remaining questions according to this standardized under-

TABLE 1

Descriptions and examples of recall, algorithmic, and conceptual question categories

<i>Question category</i>	<i>Description</i>	<i>Example</i>
Recall	Recall, recognize, list, describe, identify, retrieve, or name previously learned material	List the postulates of the kinetic theory of gases
Algorithmic	Solve problems through the use of mathematical equations; questions typically require manipulation of the different variables of the equation	At 750 mmHg, nitrogen occupies 800 mL. The gas is compressed to a final volume of 400 mL at the same temperature. What is the final pressure?
Conceptual	Justify a choice, predict what happens next, explain why and how something happens, link two or more areas or topics, or extract useful data from an excess of information	There is no one type of conceptual question. See Tables 2 and 3 for extensive descriptions and examples

standing. During this analysis, whenever the second author was unsure about the categorization of a particular question, both authors discussed the problem and jointly categorized the question. Additionally, the authors determined the intra-rater reliability of their categorizations. A different set of 20 questions was selected and analyzed at two different times by the second author. The results of these analyses were compared, and it was concluded that 100% intra-rater reliability had been reached (Gay & Airasion, 2000).

## RESULTS

In organizing the results of the study, it was determined that textbook questions should be grouped according to their location and functionality in the unit of study (i.e. warm-up motivation, example, exercise, problem, or test). The 456 gas law questions found in the seven textbooks examined revealed 27 warm-up motivation, 141 example, 54 exercise, 120 problem, and 114 test questions. Similar functionality for the teacher-generated questions was not possible since purpose cannot be inferred from item placement in an examination.

Warm-up motivation questions in the unit opening section provided a brief introduction to the material and established intention prior to instruction. These open-ended questions were oftentimes related to events that students encounter in their daily lives and were intended to increase their interest in the subject and encourage them to make their own inquiries about the topic.

Example questions focused on the stoichiometric relations and formulae used during the unit. A sample question, the method for solving the problem, and the answer were provided to illustrate how to solve such questions before students do so on their own.

Exercise questions immediately followed example questions and asked a question very similar to that example; however, exercise questions require students to discover the answer. It was found that these questions were typically open-ended and algorithmic in all of the textbooks.

Problem questions were usually open-ended and given at the end of the unit. Although a few questions were original, these were usually in a similar format to the example and exercise questions; many were nearly identical to previously asked example and exercise questions with just a few changes to the numbers or figures provided.

Test questions resembled problem questions in terms of their content and were placed immediately after them. Almost all test questions were written in multiple-choice format.

### *Findings Concerning Textbook Questions*

Table 2 illustrates that the 456 textbook questions were distributed across the three categories: 20 recall (4.39%), 285 algorithmic (62.5%), and 151 conceptual (33.1%). The ConQ referred to here as particulate, tiered, analogy, and series completion did not appear in any of the textbooks, whereas laboratory and demonstration questions were found in most textbooks (Table 3). However, the quantities of laboratory and demonstration questions are rather small: 11 laboratory (about 2%) and five demonstration (about 1%). The large majority of the ConQ ( $n=151$ ) provided in the textbooks fell under the ParConQ category ( $n=135$ ). Small percentages of the ParConQ were distributed across modified recall, modified calculation, and qualitative answer with reason questions together ( $n=63$ ), while a larger percentage was extra data questions ( $n=72$ ).

### *Findings Concerning Teacher-Generated Examination Questions*

The 264 teacher-generated examination questions were distributed across the three categories: 7 recall (2.65%), 63 algorithmic (23.86%), and 194 conceptual (73.49%). There is similarity between the distribution of RecQ in both the teacher-generated and textbook questions analyzed. However, there is very little consistency between the distributions of AlgQ and ConQ found in the textbooks and those generated by teachers. It was observed that teachers tended to ask many more ConQ than the textbooks

TABLE 2

Distributions of textbook questions according to recall, algorithmic, or conceptual categories ( $N=456$ )

<i>Textbook no.</i>	<i>RecQ</i>		<i>AlgQ</i>		<i>ConQ</i>	
	%	<i>f</i>	%	<i>f</i>	%	<i>f</i>
1	–	–	12.28	56	6.80	31
2	–	–	10.31	47	4.61	21
3	2.85	13	9.21	42	2.63	12
4	0.22	1	9.43	43	4.83	22
5	–	–	10.31	47	5.04	23
6	1.32	6	5.70	26	5.48	25
7	–	–	5.26	24	3.73	17
Total	4.39	20	62.50	285	33.11	151

TABLE 3

Distributions of textbook questions according to type of ConQ ( $N = 456$ )

Textbook no.	<i>ConQ<sup>a</sup></i>				<i>Partially conceptual questions</i>							
	<i>L</i>		<i>D</i>		<i>MR</i>		<i>MC</i>		<i>QAR</i>		<i>ED</i>	
	%	<i>f</i>	%	<i>f</i>	%	<i>f</i>	%	<i>f</i>	%	<i>f</i>	%	<i>f</i>
1	0.22	1	0.22	1	0.44	2	0.44	2	0.44	2	5.04	23
2	0.44	2	0.22	1	0.88	4	0.22	1	0.88	4	1.97	9
3	0.44	2	–	–	0.66	3	–	–	1.54	7	–	–
4	–	–	0.22	1	0.22	1	0.88	4	0.44	2	3.07	14
5	0.44	2	0.22	1	0.88	4	0.66	3	0.44	2	2.41	–
6	0.44	2	0.22	1	1.75	8	0.88	4	0.44	2	1.75	8
7	0.44	2	–	–	0.44	2	0.66	3	0.66	3	1.54	7
Total	2.42	11	1.10	5	5.27	24	3.74	17	4.84	22	15.78	72

*L* laboratory, *D* demonstration, *MR* modified recall, *MC* modified calculation, *QAR* qualitative answer with reason, *ED* extra data

<sup>a</sup>Nil questions for tiered, analogy, particulate, and series completion types

(73% vs. 36%). Textbooks focused much more on AlgQ than teachers (63% vs. 24%).

Teacher-generated ConQ do not include tiered, analogy, particulate, and series completion questions; only 24 laboratory (9.09%) and 24 demonstration (9.09%) questions were found in the teacher-generated questions. These findings are relatively similar to those regarding the textbook questions—although there are slightly different distribution rates for laboratory and demonstration questions asked by teachers and textbooks.

The large majority of the teacher-generated ConQ fell under the ParConQ grouping ( $n = 149$ ). Modified recall (24; 9.09%), modified calculation (24; 9.09%), and qualitative answer with reason (2; 0.76%) questions together amounted to 50 questions; the 96 extra data questions represented the largest percentage (36.4%) of the questions asked.

#### *Comparison of Textbook and Teacher-Generated Questions*

Table 4 shows a comparison between the distributions of ConQ in textbook and teacher-generated questions. The influence of textbook questions on teacher-generated questions was explored using a correlation analysis. Pearson product–moment correlation coefficient ( $r$ ) is 0.885, and the correlation between distributions of ConQ in textbook and teacher-generated questions is significant at the 0.01 level.

TABLE 4

Comparison between the distributions of ConQ from textbooks and teachers

Question source	ConQ		Partially conceptual questions			
	L (%)	D (%)	MR (%)	MC (%)	QAR (%)	ED (%)
Textbook	2.42	1.10	5.27	3.74	4.84	15.78
Teacher-generated	9.09	9.09	9.09	9.09	0.76	36.40

L laboratory, D demonstration, MR modified recall, MC modified calculation, QAR qualitative answer with reason, ED extra data

## DISCUSSION

The findings of this study indicate that most of the questions in the textbooks studied are algorithmic and that, therefore, these textbooks do not facilitate or encourage student comprehension of the properties and behaviors of gases or gas law theories. Most of the questions presented in the textbooks do not have the qualities that enable students to develop conceptual understanding and gain HOCS required by the Turkish OSS entrance examination. These findings support the results of previous studies that demonstrated most textbook questions were based on mathematical calculations on the hydrodynamical laws and did not require a conceptual understanding of the material (De Berg, 1989; De Berg & Treagust, 1993; Niaz, 2000).

The findings imply that most of the teacher-generated questions in the present study are ConQ. It was observed that teachers tended to ask a higher proportion of ConQ than the textbooks (73% vs. 36%). Textbooks focused much more on AlgQ than teachers did (63% vs. 24%). On the other hand, since the large majority of these ConQ corresponded with ParConQ, it was concluded that both teachers and textbooks focus more on ParConQ, especially extra data questions, and that these questions did not require as much conceptual understanding as the ConQ. The significant correlation (0.885) between types of textbook and teacher-generated questions appears to indicate that chemistry teachers are being influenced by the types of questions in textbooks when they prepare their own questions.

It may be surprising that the percentage of ConQ in the textbooks is rather high in comparison to international standards; however, this may be related to the types of ConQ and their nature. The findings show that ConQ consists of both ConQ and ParConQ for both Turkish high school chemistry textbook and teacher-generated questions. That is, tiered, analogy, particulate, laboratory, demonstration, and series completion type ConQ require a greater conceptual understanding and different cognitive skills. However,

ParConQ led to only a marginally conceptual understanding of the material. In this study, it was concluded that most of the ConQ are indeed ParConQ and that extra data questions are dominant among all the ConQ in Turkish high school chemistry textbooks. Extra data questions may lead to HOCS to a certain degree compared with other ParConQ since these questions require translation of information from representation to symbols.

From these results, it can be concluded that it is not enough for chemistry educators, textbook writers, and teachers to analyze questions using only the categories of conceptual, algorithmic, and recall because the ParConQ embedded in the conceptual category may mask the lack of effects on learning and HOCS. The framework of question types that ignores the importance of analyzing the various types of ConQ and assumes that all ConQ will promote HOCS leads to a high degree of error. For example, Coştu (2007), whose study was conducted in Turkey as well, noted that students tended to do best on ConQ among the conceptual, algorithmic, and graphical questions. However, after examining the conceptual and graphical question samples used in Coştu's study, we found that the ConQ were actually ParConQ and that the graphical questions were in fact laboratory ConQ.

### *Implications*

The major implication of this research is the need for teachers, textbook writers, and academics to consider the types of ConQ when creating questions or analyzing chemistry questions at all educational levels. Each ConQ type requires a different set of cognitive skills. For example, there has been growing interest in graphing skills (Roth & McGinn, 1997). Brasell & Rowe (1993) suggested that graphs are an important means of communicating scientific data, and Berg & Smith (1994) pointed out that graph construction and interpretation abilities are critical to understanding and conveying information in science.

Furthermore, particulate type ConQ in chemistry represent situations on an atomic or molecular level; for example, solving problems using microscopic visual representation and comprehending the relationship between microscopic and macroscopic levels. Many studies of student problem-solving abilities have indicated their difficulties with particulate ConQ (Bennett et al., 2003; Mulford & Robinson, 2002; Nurrenbern & Pickering, 1987; Pickering, 1990). Since students oftentimes fail to understand the relationships among the three levels of chemistry (macroscopic, microscopic, and symbolic), they may encounter difficulties or misconceptions regarding chemistry topics. Pickering discussed this difficulty by stressing the microscopic level of chemistry in problem solving:



Presumably instructor and textbook emphasis has caused students to direct their efforts toward problem solving. But the ability to solve a problem, while desirable in itself, does not seem to imply much real understanding of microscopic reality, and it is this understanding that is at the heart of chemical science (p. 255).

Understanding the microscopic level of chemistry and the relationship between the various levels is fundamental for developing a comprehension of the nature of chemistry. Therefore, it is important that teachers and textbooks employ particulate type questions as well as other types of ConQ.

Finally, ConQ appear to affect the conceptual development of students in diverse ways; consequently, it is not effective to stress only one type of ConQ while ignoring the others. Thus, textbooks should include different ConQ types and teachers should prepare lesson plans and examinations that touch upon each type. Prospective chemistry teachers should be instructed in methodology courses about the types of ConQ and how to prepare questions of each type. These methodology courses should take specific care to emphasize the importance of students developing a conceptual understanding of chemistry. Additionally, during in-service workshops, experienced chemistry teachers should acquire new knowledge and skills with the types of ConQ and their preparation.

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#### APPENDIX 1

Turkish textbooks used in the study\*

1. Arık, A., & Polat, R. (2002). Grade-10 High School Chemistry Textbook, Oran yayıncılık, İzmir.
2. Dalkılıç, I., & Dalkılıç, N. (2002). Grade-10 High School Chemistry Textbook, Mega Yayıncılık San. ve Tic. Ltd. S., Ankara.
3. Dursun, M. F., Gülbay, İ., Çetin, S., Tek, Ü., Özkoç, F. F., & Güntut, M. (2009). Grade-10 High School Chemistry Textbook, Milli Eğitim Bakanlığı, İstanbul.
4. Karaca, F. (1998). Grade-10 High School Chemistry Textbook, Pasa Yayıncılık Ltd., Ankara.

5. Kızıldağ, G., & Dursun, M. F. (2000). Grade-10 High School Chemistry Textbook, MEB Devlet Kitapları, Ankara.
6. Varol, Ş., & Gürocak, M. (2002). Grade-10 High School Chemistry Textbook, Bilim ve Kültür yayınları Limitet Şirketi, Ankara.
7. Yılmaz, F. (1999). Grade-10 High School Chemistry Textbook, Serhat Yayınları, İstanbul.

\*Certificated for use by the Board of Education and Training, Ministry of National Education, Republic of Turkey.

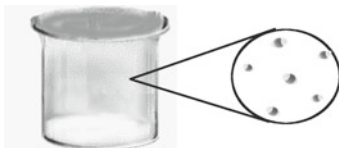
## APPENDIX 2

### *Descriptions, examples, and source of question types*

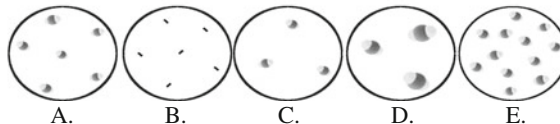
#### A. Conceptual questions

**PARTICULATE.** A chemical situation is represented on the atomic or molecular (particulate) level, using circles or spheres of different sizes or colors to represent the particles.

A magnified view of a sample of carbon dioxide ( $\text{CO}_2$ ) gas at a pressure of 1.0 atm is shown below.

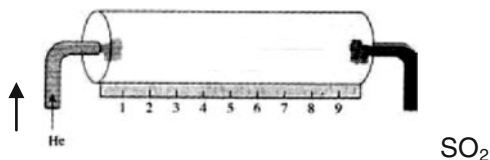


Which of the following diagrams best describes what you would "see" on the same area at a reduced pressure of 0.5 atm?



[<http://jchemed.chem.wisc.edu/JCEDLib/QBank/collection/CCInventory/JCE2006p0954QB/JCE2006p0954W.doc>]

**DEMONSTRATION.** Questions answered after observing a demonstration, video, or simulation.



As seen in the figure, when helium gas and sulfur dioxide gas are released at the same time from opposite ends of a tube at the same temperature, where will the gases meet?

- (a) 2
- (b) 4
- (c) 5
- (d) 6
- (e) 8

[Textbook #4]

TIERED. Consists of a pair of questions: the first is a multiple-choice problem and the second is the reason for that answer.

Which of the following will occur when neon gas confined in a container is heated?

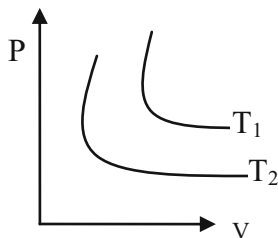
- (a) The gas molecules only collide with the walls of the container
- (b) The speed of the gas molecules decreases
- (c) The number of collisions between the gas molecules and the walls of the container decreases
- (d) The number of collisions between the gas molecules and the walls of the container increases
- (e) The pressure of the gas on the walls of the container remains constant

What is the reason for your answer?

- (a) The gas molecules are separated by comparatively large distances
- (b) The average kinetic energy of the gas molecules decreases
- (c) The pressure of the gas on the walls of the container decreases
- (d) The pressure of the gas on the walls of container increases
- (e) The pressure of the gas on the walls of container does not change since the volume is constant

[Authors]

LABORATORY. Use of graphs, tables, and other data to predict and/or explain what happens in an experimental situation



The pressure–volume curves for a gas at two different temperatures ( $T_1$  and  $T_2$ ) are shown in the figure. Which temperature is higher? Explain your answer.

[Textbook #7]

ANALOGY. Based on completing an analogy (A is to B as C is to D); question stem contains the first part of the analogy (A is to B as); the alternate that best completes the analogy is selected (C is to D).

[An analogy example regarding gas laws could not be found]

SERIES COMPLETION. Based on selecting an item that best completes a series, recognizing the common feature in the series, and using that feature to complete the series.

What gas comes next in the following series that relates to the escape of gases into a vacuum through a tiny orifice:  $H_2$ ; He;  $NH_3$

- (a)  $CO_2$
- (b)  $Cl_2$
- (c)  $N_2$
- (d)  $SO_2$

[Authors]

## B. Partially conceptual questions

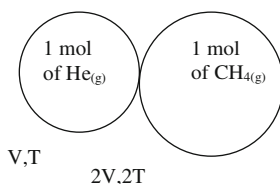
**MODIFIED RECALL.** Modification of a question that requires recalled information; new question requires interpreting previously memorized information or translating the concepts behind the information to a new setting.

In which set of the following pressure–volume conditions do  $n$  moles of gas  $X$  behave the most like an ideal gas?

- (a)  $T=298\text{ K } P=1\text{ atm}$
- (b)  $T=323\text{ K } P=0.5\text{ atm}$
- (c)  $T=250\text{ K } P=0.5\text{ atm}$
- (d)  $T=298\text{ K } P=0.5\text{ atm}$
- (e)  $T=298\text{ K } P=0.5\text{ atm}$

[*Teacher-generated*]

**MODIFIED CALCULATION.** Modification of a question that requires use of algorithmic calculation; new question requires a qualitative rather than quantitative answer.



Which of the following values are equal for the gases He and CH<sub>4</sub> as seen in the figure?

- (a) Number of molecules colliding with the walls of the container
- (b) Pressure
- (c) Density

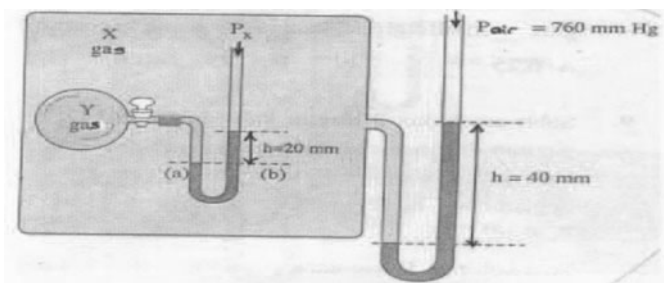
[*Teacher-generated*]

QUALITATIVE ANSWER WITH REASON. Modification of a recall question or an algorithmic calculation; new question requires a qualitative answer and an explanation of the reasoning for that answer.

How does a balloon's volume change when placed near a warm radiator? Explain your reasoning.

[Textbook #2]

EXTRA DATA. Solution of a problem using a visual representation of the data (e.g. a figure or illustration of an experiment) and extra data or data in an unexpected format; questions require a representation where some of the extra data is placed and there is a translation of information from representation to symbols.



In the apparatus shown in the above figure, the container filled with gas Y is inside the container filled with gas X. The open-air pressure is 760 mmHg. When the open-air pressure is decreased to 750 mmHg, which of the following answers correctly describes the change that will be observed in height of the Hg in columns a and b of the monometer?

- (a) There will be no change
- (b) There will be an increase of 10 mm in column a
- (c) There will be an increase of 10 mm in column b
- (d) There will be an increase of 20 mm in column a
- (e) There will be an increase of 20 mm in column b

[Textbook #4]

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