PROBLEM-SIMILARITY RECOGNITION AND PROBLEM-SOLVING SUCCESS IN HIGH SCHOOL CHEMISTRY

by

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(ABSTRACT)

This was an investigation of the differences in student recognition of problem similarity in high school chemistry, the relation of problem-similarity recognition to problem-solving success, and the improvement in problem-solving success subsequent to consideration of problem similarity.

Tests developed for this study were used to measure initial problem-solving success, problem-similarity recognition using a 4-point context-to-structure scale, and final problem-solving success. The sequence of measurements was: (1) problem-similarity recognition prior to writing problem solutions, (2) problem-solving success, (3) problem-similarity recognition after writing problem solutions, (4) problem-similarity recognition after being given problem solutions by the teacher, and (5) problem-solving success.

Analyses of the data indicated that the most successful problem solvers differed from the moderately successful and the least successful problem solvers in their tendency to recognize problem similarity according to structure rather

than context. Additionally, the most successful as well as the least successful problem solvers improved in problem-solving success subsequent to their consideration of problem similarity.

Recommendations for instruction and for additional studies are included.

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CHAPTER I

INTRODUCTION

Ausubel (1978) directs teachers to determine what the student knows, and to teach accordingly. In less directive manner, Polya (1973) advises teachers, through his simple, powerful questions for problem solvers, to consider the student's previous experiences. "Have you seen it before? Or have you seen the same problem in a slightly different form" (p. xvi)? In practice, teachers neglect this important component of teaching and learning: what the student already knows. As a result, teachers fail to fully understand or explain student success and failure during instructional activities such as problem solving. If teachers are to foster more successful learning during these activities, they must identify the variations in what students know.

Studies have already identified variations in what students know and do during mathematical problem solving. In addition to differing in success at solving mathematics problems, students differed markedly in recognition of similarity among problems, according to studies by Krutetskii (1969, 1976) and Silver (1979, 1981). Some students recognized the structural similarity in problems having similar steps in their solutions. Other students failed to recognize structural similarity, but recognized similarity in problems having similar contexts such as identical numeric values and other specifics. While the students who recognized structural similarity were successful problem solvers, the students recognizing only contextual similarity were less successful at solving mathematics problems. Such differences among students cause cumulative, increasing variations in what they bring to mathematics problem solving.

Even though problem solving is an important part of teacher instruction and student performance in high school chemistry, there are no studies of problem-solving success and problem-similarity recognition in high school chemistry reported in the literature. Transfer from the mathematics literature is difficult due to the added chemistry concepts; behavior during chemistry problem solving may be different from mathematics problem-solving behavior. The mathematics content of high school chemistry problems presents little difficulty to the students. The students' difficulty with chemistry problems seems to be due to the problems' chemistry content. For example, a problem such as

$$24 + 19 + 19 = 62$$

is trivial a exercise for chemistry students. However, some chemistry students have difficulty generating that same solution as the answer to:

What is the molar mass of magnesium fluoride?

Molar mass of magnesium = 24

Molar mass of fluorine = 19

24 + 19 + 19 = 62

Some students continue to have difficulty with chemistry problems, even after their teachers expect all students to have mastered the chemistry content of the problems. For less successful students, new chemistry content and additional problems exacerbate the difficulty and they fall even further behind more knowledgeable students. The disparity between what some students know and what teachers expect them to know increases steadily in contrast to the more successful students who meet the teachers' expectations as the chemistry course progresses.

As students attempt to solve new problems, what they already know continues to affect their problem-solving success and their development of chemistry concepts. Teachers attempting to understand the students' successes and to deal with their failures should consider more fully variations in what they know.

The mathematics studies suggest that such variations are manifest in a student's ability to recognize structural similarity and contextual similarity. Differences in recognition of structural and contextual similarities can be identified by comparing the problems that different students consider as similar. Moreover, the basis the students use for similarity classification can be identified by examining the problems described as similar.

This study examined chemistry student's recognition of structural and contextual similarity, and the relation of problem-solving success to problem-similarity recognition. The hypotheses of primary concern were:

(1) More successful problem solvers will tend to recognize problem similarity according to structure: (a) prior to writing a solution to the problem, (b) after writing a solution to the problem, and (c) after teacher presentation of the solution.

(2) Less successful problem solvers will tend to recognize problem similarity according to context: (a) prior to writing a solution to the problem, (b) after writing a solution to the problem, and (c) after teacher presentation of the solution.

(3) Problem-solving success will improve subsequent to consideration of problem similarity.

Evidence of recognition of problem-structure similarity was operationally defined as a high score on the Similarity Choice Test (to be described).

Evidence of recognition of problem-context similarity was operationally defined as a low score on the Similarity Choice Test.

A limitation of this study was the non-random selection of its subjects. In order to extend the findings to all chemistry students, additional studies are required.

Justification

The primary justification for this study is its relevance to instruction in high school chemistry. Chemistry instruction features problem solving, not simply to produce answers to specific problems but as a device for studying and learning chemistry content. As variations develop in students' knowledge of chemistry content, differences in their problem-solving success occur. Teachers who identify and consider content knowledge variations among students are in a much better position to design instruction that better serves all students.

This study provides information about two components of student differences: problem-similarity recognition and problem-solving success. These components of student differences are closely related to student learning in chemistry and lend themselves to consideration when teachers plan instruction. If problem-similarity recognition differs from student to student while being related to problem-solving success, then problem-similarity recognition can serve as a feature of instruction involving problem-solving.

The current emphasis on problem solving in school science and mathematics constitutes important, additional justification for the study. This emphasis is consistent with the traditional inclusion of problems in high school chemistry. Renewed interest in problem solving throughout the professional community is exemplified by the statement of the National Council of Teachers of Mathematics (1980): "Problem solving must be the focus of school mathematics in the 1980s" (p. 2).

Problem-solving skill was one of the five major goals of science education included in the National Society for the Study of Education 59th Yearbook, Rethinking Science Education (1960). The National Science Teachers Association's (1970) position on critical issues confronting science teachers included the need for students to study problems. Drawing on their historical study of a sixty-year period in science education, Champagne and Klopfer (1977, 1981) described the present interest in problem solving:

> On one aspect of science teaching, there is a remarkable degree of agreement in the professed beliefs of most science educators today--the belief that problem solving...play(s) an important role in children's learning of science in school (p. 3).

The intense current interest in problem solving includes a specific concern for applying and using mathematics during study of science and other content areas. Webb (1979) discussed the added dimension problems have in an applied-content area, and the importance of using such applied-content problems for research and instruction.

> Applied problems as used in problem-solving research may evoke different behaviors and solution processes from those evoked by problems in pure mathematics.... Because of their special nature, applied problems deserve special attention in research and in the teaching and learning of mathematics. A greater understanding of this content variable would facilitate the increased use of applied problems in instruction (p. 88).

An applied problem in high school chemistry includes chemistry information and mathematics information. The chemistry information in the problem requires the student to identify and employ the appropriate chemistry concepts in order to reduce the problem to a mathematical statement. The mathematics information in the problem requires the student to execute the appropriate operations such as addition, subtraction, multiplication, division, and exponentiation.

This study used applied problems in chemistry to determine if successful chemistry problem-solving was related to recognition of problem similarity. Problem solving is especialy important in high school chemistry. It is not simply a means of obtaining answers, although problem solutions often provide useful information. Rather, problem solving is a process of relating new information to existing chemistry concepts, and even developing new concepts. The basis for the study is work by V. A. Krutetskii and colleagues in the Soviet Union and work by E. A. Silver in this country. Their work, discussed more fully in Chapter II, indicates that mathematics students differ not only in obtaining correct solutions to mathematical verbal problems, but also differ in recognition and recall of similar information in problems.

Structure of problems, prominent in Krutetskii's and Silver's studies, is one of several characteristics used by Kilpatrick (1979) and others to describe problems and problem-solving (Barnett, 1979; Goldin, 1979; Kulm, 1979; Webb, 1979). Problem syntax, the arrangement and choice of words and symbols, helps describe a problem. Problem context, the incidentally specific words and symbols, further describes a problem. Problem content, the subject matter that gives the problem meaning, partially describes the problem. Problem structure adds to the problem description and includes the representation of the problem solution. These four characteristics of problems were considered during the development of the problems in this study.

Summary

The primary justification for this study is its implications for improving instruction. The study focused on problem solving, an important part of high school chemistry that is currently of considerable interest in the professional community. The study determined the differences in student recognition of chemistry problem similarity, the relation of chemistry problem-solving success to recognition of chemistry problem similarity, and the improvement in chemistry problem-solving success subsequent to multiple testing for problem-similarity recognition. Results of the study will be useful in designing instruction which includes explicit teaching involving problem-context and problem-structure similarities in order to improve student success during problem solving in high school chemistry.

CHAPTER II

SURVEY OF RELATED LITERATURE

This report of related literature contains two sections. The first section includes a summary of David P. Ausubel's theory of learning. The second section features an account of V. A. Krutetskii's work with mathematics students, and includes reports of other studies dealing with the problem variables involved in this study.

Ausubel's Learning Theory

Ausubel's (1968) statement of principle underlying learning and instruction is, "The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly" (p. vi). The learner's existing knowledge influences not only the new information that is noticed, but also the meaning given the new information through relating it to existing knowledge. In addition to his emphasis on the importance of the learner's existing knowledge, Ausubel describes separate attributes of learning: discovery-reception and rote-meaningful. There are variations both in mode of encounter and in process of giving meaning during learning. The encounter with new information and the attachment of meaning to new information are related but distinct processes. (Ausubel, 1968; Ausubel, Novak, & Hanesian, 1978).

Attributes of Learning

Ausubel (1968) describes meaningful learning as a process of relating new material to existing, relevant knowledge:

> The essence of the meaningful learning process...is that symbolically expressed ideas are related in a nonarbitrary and substantive (nonverbatim) fashion to what the learner already knows (p. 37-38).

Rote learning, for Ausubel, is the process of making arbitrary connections between existing knowledge and new information. Some material, such as the spelling of 'son' and 'sun', requires rote learning. Joseph Novak (1977a), in discussing Ausubel's work, states:

> Meaningful learning is a process in which new information is related to an existing relevant aspect of an individual's knowledge structure (p. 74).
>
> Some types of information are inherently meaningless: telephone numbers, nonsense syllables, and other information cannot be linked in substantive ways . . . and must be arbitrarily stored (p. 77).

If new information has meaning in terms of knowledge the learner lacks, it can only be learned in a rote manner.

Rote learning may also occur if the student fails to become conscious of the relation between existing knowledge and new information.

Another attribute of learning is the manner, varying from reception through discovery, in which new material is encountered. During reception learning, the new information and its relation to existing concepts are explicitly described to be the student. Ausubel (1968) explains:

> The principle content of what is to be learned is typically presented to the learner in more or less final form. Under these circumstances, the learner is simply required to comprehend the material and incorporate it into his cognitive structure so that it is available for either reproduction, related learning, or problem solving at some future date (p. 83).

During discovery learning, the student seeks new information and establishes its relation to existing knowledge. The student may then be given the customary label for the information or the relation. Ausubel, Novak and Hanesian (1978) state that the difference between reception learning and discovery learning "inheres in whether the principal content of what is to be learned is discovered by or is presented to the learner" (p. 60)

All meaningful learning, acquired by any variation in mode from reception through discovery, involves a degree of discovery in that the learner actively establishes the relation between new information and existing knowledge, and does so in a nonarbitrary way. Meaningful learning, for Novak (1979), is "always ideosyncratic and in this sense the learner 'discovers'" (p. 467).

Problem Solving as Learning

Some of the differences in students' performances during high school chemistry problem solving are due to differences in their existing knowledge. Differences in student performance may also be due to the new relations, somewhat characteristic of the learner, that are established between information in a new problem and existing concepts, and developed in part through previous experiences with problems.

Less successful problem solvers not only may lack usefully relevant concepts but also may be establishing new, less useful relations with existing concepts. If a student related a new problem to existing information which was not directly involved in a successful solution, the student may be unable to solve the problem. For this student, problem solving may involve noticing some information, finding the information to be related to nothing else in existing knowledge that seems useful, and failing to solve the problem. The less successful problem solver may also resort to assigning individual, arbitrary meaning to the information in a problem, in an effort to remember it.

More successful problem solvers are likely to be relating information in a new problem to relevant concepts in a substantive manner. A student who relates information in a problem to existing knowledge that includes the facts and processes needed for the solution is more likely to solve the problem successfully. For this student, problem solving is an opportunity to assimilate problem information and develop even more useful concepts. Novak (1977b) comments:

> Major changes in meaningful learning (or use of knowledge in problem solving) occur . . . (as) specifically relevant concepts in cognitive structures (p. 456).

Additional experiences with problem solving may result in meaningful learning for the successful problem solver, while tending to result in rote learning for the less successful one.

Concepts, developed from perceived regularities in events, are somewhat characteristic of the learner and therefore do vary from person to person in their detail and their relation to other concepts. A student who is perceiving similarity among problems is developing concepts that describe commonalities among the problems. If the concepts include relations essential to the construction of the solution, the student has something to work with, cognitively, to develop the solution. The student who fails to become conscious of problem similarity involving important, useful information may not be developing concepts potentially useful for problem solving.

Problem-Solving Research

The research reported in this literature survey included the problem variables involved in this study. The major sources was the report of work by V. A. Kruteteskii, who directed a long-term, extensive study of mathematics students.

Krutetskii's Studies

Krutetskii (1969, 1976), working with colleagues in the Soviet Union, directed an eleven-year Soviet research program that explored the nature and structure of mathematical abilities. Krutetskii used the results from questionnaires sent to mathematics teachers and mathematicians, biographies of mathematicians and physicists, assumptions of abilities in school mathematics curriculum, school records of over 1,000 students, and case studies of several exceptionally mathematically gifted children to develop a list of rather specific mathematical abilities. A summary of the abilities includes:

(1) Isolate form from content: operate with formal structures.

(2) Detect what is of chief importance; abstract from the irrelevant; see what is common to the externally different.

(3) Operate with numerals and other symbols.

(4) Employ sequential, properly segmented, logical reasoning.

(5) Think in curtailed structures; shorten the reasoning process.

(6) Reverse a mental process.

(7) Switch from one mental operation to another.

(8) Remember mathematical information.

(9) Develop spatial concepts.
(Krutetskii, 1976, p. 87-88)

About two hundred school children, ages 6 to 17, were classified according to their mathematical ability by their mathematics teachers: very capable, capable, relatively capable, average, and relatively incapable. The students were asked to think aloud as they solved various series of problems, being given help by the teacher-researcher for some series. Krutetskii examined the results of the interviews, and developed a description of three stages during problem solving and of several abilities involved in each stage.

According to Krutetskii's (1976) report, the first stage of problem solving is the period of gathering information needed to solve the problem. Success during this stage depends in part on relating the problem to existing knowledge, recognizing the important material in the problem, and identifying what is superfluous. The second stage involves processing information during problem solving. This stage calls on several abilities, including specific knowledge such as content from physics, mathematics knowledge, recognition of similarity to other problems, and comparison with related, easier problems. The third stage of problem solving involves retaining information about the solution, and includes the ability to recognize the generality of the solution and to recognize the similarity of the solution to past solutions.

During the period of gathering information needed to solve the problem, less capable students have difficulty forming any useful association between concrete terms of a specific problem. Average students recognize separate items of information in the problem, but tend to forget a specific part as they try to establish relations among parts. More capable students recognize the different items of information and seek relations among them. These more capable students differentiate three kinds of information:

(1) Information required for the given type of problem.

(2) Information not required for the given type of problem, but required for the example.

(3) Information not required for the example.

Krutetskii (1969) elaborates on the description of the capable student:

> By recognizing the principle underlying an initial problem of a given type, it

> is easy for the capable pupil to solve other problems of the same type. He is able to recognize each subsequent problem of this type as one of the variants (a "duplicate", as one of them put it) of a general type of problem. He is not disturbed by the fact that one problem concerns rabbits and others, rubles or kilometers (p. 37).

During the second stage of problem solving, processing information, students continue to exhibit differences. Capable students tend to solve the problem, even a novel problem, in general form. They tend to generalize during the first encounter. Krutetskii (1969) points out that "every generalization is supported by a comparison of similarities (p. 40)." Capable students recognize the similarities quickly; however:

> Average pupils form individual, concrete associations that are related only to a given problem, but only gradually, as a result of exercises, are they able to make generalizations. Less capable pupils have difficulty.... For them, generalization is even more difficult, and in some cases, impossible (Krutetskii, 1969, p. 41).

Less capable students attempt to solve several problems of the same type as though each were a different type. They have difficulty perceiving the general in the problem.

During the third stage of problem solving, retaining information about the solution, students differ in the material they recall. Capable students tend to remember the problem solutions type and general nature, but not its specifics.

In summary, mathematics students perform differently during problem solving. They differ in generalizing the solutions to problems with similar structures. They differ in recognizing the information that is specific to one problem. And they differ in recalling the structure-relevant and context-relevant information from past problems.

Problem-Variables Studies

E. A. Silver, drawing on Krutetskii's work, devised studies to investigate problem-similarity recognition. Silver (1979, 1981) examined the relationship between student performance on achievement tests and problem tests, and student perception of problem similarity. He also studied the recall of problem information.

Silver's first investigation used eighth-grade mathematics students. The students were given a pre-test for perceived problem similarity, a problem solving test followed by teacher presentation of the solutions, a post-test for perceived problem similarity, an additional test for problem similarity (used only with one group of students), and several achievement tests.

The pre- and post-tests of problem similarity required students to form groups of similar problems. The problems were written to vary in either structure or context.

However, students formed groups with unanticipated similarities. Silver later modified the problems to better control possible student grouping. The problem-solving test included the problems used for the pre- and post-tests for similarity. For the additional test for problem similarity (used only once), students were asked to think about how they would solve each problem and to identify the problem-solving test problem that was mathematically related to the new problem. The achievement tests were the Educational Records Bureau Mathematics Achievement Test and three subtests of the Differential Aptitude Test.

Silver obtained significant positive correlation (r = 0.31 to 0.52, $p < .005$) between problem solving test scores and perception of similarity based on structure scores. The correlation between structure-similarity perception and problem-solving success was significant (r = 0.42 to 0.44, $p < .005$) after the effects of I.Q. scores were removed.

Silver's second investigation used seventh-grade mathematics students. The students were given the test for perceived problem similarity prior to their attempting to solve the problems. Their tendency to recall information about structure or about detail (context) was measured by analyzing their responses to two initial problems and six subsequent problems. Each initial problem was related to one subsequent problem in structure, to a second subsequent problem in detail, and was unrelated to a third subsequent problem.

For each subsequent problem, the subjects were asked to recall any initial problem which was mathematically related. Recall of information was also measured on five occasions by obtaining (in writing) as much information as the students could remember about each initial problem: (1) immediately after attempting to solve the problems, (2) the next day, (3) immediately after being given the correct solutions, (4) the next day, and (5) about four weeks later. Problem solvers classified in the top third on the problem-solving test tended to recall structure; problem solvers in the bottom third did not. All the good problem solvers identified the initial problems and their subsequent structure-related problems as being mathematically related.

In general, Silver's work with seventh- and eighth-grade mathematics supports Krutetskii's analysis of the performance of mathematics students 6 to 17 years old. Silver found that more successful problem solvers tended to use structure as the basis for problem similarity. The good problem solvers in his studies also differed from poor problem solvers in the tendency to recall the structure of mathematics problems.

Silver's studies featured context and structure variables. Two other variables, syntax and content, have been found useful for describing a problem. While each type of variable describes a different set of characteristics of the problem statement, the distinction between any two of them is somewhat arbitrary.

The syntax of the problem statement describes the choice and arrangement of words in the sentence. For problem statements presented in verbal form, syntax affects initial comprehension of the problem. Aspects of syntax include such characteristics as number of words, length of each word, complexity of phrasing, and clustering of data presented in the problem. As each of these variables changes value, the difficulty of the problem may change. An increase in number of words and symbols used to phrase the problem statement may cause an increase in difficulty by making a considerable demand on short-term memory. In a similar manner, more phrases and more grammatical complexity may affect comprehension to the point of preventing the student from understanding the problem statement. A change in clustering of data by separating the data items in the problem statement may increase the student's difficulty in processing the data. If the data is presented in a sequence different from the order of its use in the solution, the difficulty may increase due to increased work in short-term memory. Posing the question first rather than last may affect the student's consideration of data in terms of the question. In general, a given problem can be phrased in ways that vary from brief, simple statements to longer, more complex statements that are more difficult for the student to comprehend.

Ability to understand the syntax of the problem statement is necessary for initial comprehension as the student reads and interprets the written material. Research investigating the relation between mathematics achievement and reading ability generally reports a positive correlation that sometimes increases after instruction in reading. Reviews of such research indicate sizeable correlations between reading and mathematics achievement (Aiken, 1972) and between reading and problem solving (Hollander, 1978). Gilmary (1967) and Henney (1969) obtained significant improvement in arithmetic achievement for fourth-graders who had received reading instruction.

Barnett (1979) describes a verbal information processing model as it considers syntax to affect the decoding stage of problem solving. The student decodes written material, encodes its information as mathematical statements, and performs computations with the translated information. Attributes of syntax such as length, grammatical complexity, and sequence of data affect decoding of information. As the student reads the material, organizes information, stores information in short-term memory, and recalls information in long-term memory, these syntax variables become important.

Just as aspects of syntax are useful for describing problem statements, so context also helps describe a problem and contributes to ease or difficulty of comprehension. Context refers to the directly observable, incidentally specific variations in the problem. It is interesting to note that Webb (1979) describes context as the inessential characteristics of the problem. While context variations do not affect the structure of the solution, they may establish a threshold of difficulty that prevents a student from successfully constructing the resolution. Context characteristics establish the verbal setting of the problem, which may vary from concrete to abstract, from familiar to the unfamiliar, or from factual to hypothetical. Variations in numerical values or in concrete examples are context variations.

The common use of a story for a problem setting is a context variation generally considered to promote problem-solving success by engaging the student's attention. However, a story setting can become so difficult in syntax that it hinders problem-solving success due to excessive information. A specific setting does not always affect success at problem solving. Cohen and Carry (1978) found no significant relationship between the student's interest in a context (scientific, outdoor, computational) and the student's problem-solving score. Dunlop and Fazio (1979) found that students do not always use their stated preference (concrete or abstract) during problem solving. A problem with an abstract or a hypothetical setting is generally found to be difficult for more students than a problem with a concrete or a factual setting (Feldhusen and Hartz, 1975; Goldin and Caldwell, 1979).

In addition to syntax and context, problem content helps to describe a problem statement. A problem involves mathematical information and may involve information from a field of mathematical application such as chemistry. Variations in kinds of mathematical and applied-field information are content variables. The mathematical information can be classified in broad terms such as algebra or geometry as well as in more narrow classifications such as rate problems or money problems. In addition to its mathematical information, an applied problem involves essential content information from its field of application, such as genetics problems in biology or gas laws problems in chemistry.

Syntax, context, and content variables generally tend to describe a problem statement but do not describe the steps in the solution. Structure variables describe the solution of the problem. The structure of a problem includes the initial step or statement in the solution, the sequence of steps or statements that transform the initial step, and the final step or statement or goal. Some structure variables are: (1) number of steps in shortest solution, (2) nature of operations in the solution, (3) number of different operations in the solution, and (4) number of equations and unknowns.

Several studies have investigated performance on problems which have similar structures. Waters (1979) investigated concept formation during tasks with similar structures but with different degrees of abstractness and diversity. When the more abstract and diverse problem was presented first, performance on the second problem was facilitated. In a study by Reed and Abramson (1974), the effect of specification of a subgoal depended on the number of legal moves in the solution. Specifying a subgoal to the subjects significantly improved their performance on the problem with more legal moves in its solution, but not on the problem with fewer legal moves. Simon and Reed (1976) found that subjects tended to improve their strategy after simple hints or following initial success with a problem of similar structure. In reviewing structure-variables research, Goldin (1979) reported that the number of steps and the number of different operations in the solution significantly affect problem difficulty.

Summary

Ausubel describes the knowledge the student brings to a task as affecting what the student learns from the task. For problem solving, student knowledge includes what was learned during previous problem solving. The relation the student establishes between existing knowledge and new information at the time of solving the problem also affects what is learned. The relation may include the recognition of similarity between problems. The student who recognizes and recalls problem similarity based on information involving structure would seem to have an advantage over one who recognizes or recalls problem similarity based on contextual rather than structural information.

Studies by Krutetskii and Silver indicate that better mathematics problem solvers do tend to recognize and recall structure similarity. Other literature on problem-solving studies in mathematics supports the idea that syntax, context, content, and structure are important variables which affect problem-solving success. However, problems in high school chemistry contain not only mathematics content but also chemistry content. The literature does not provide a definitive statement that the findings from mathematics studies would hold for problem solving during chemistry.

This study was conducted to determine if high school chemistry students differ in problem-similarity recognition, if their problem-similarity recognition and problem-solving success are related, and if multiple testing for problem-similarity recognition affects their subsequent problem-solving success.

CHAPTER III

METHODOLOGY

Problem solving in high school chemistry typically requires a student to relate the specific, unsolved problem to available information in memory. Prior to writing the problem's solution the student has an opportunity to identify and classify information in the problem according to what the student knows. A student who recognizes similarity based only on context would relate a problem to concepts that did not necessarily involve information for constructing a correct solution. This student would tend to be unsuccessful at solving the problem. However, another student, recognizing structural similarity, might relate the problem to concepts that included useful information for constructing a correct solution. This student would tend to solve the problem correctly.

Writing a solution to the problem gives the student an opportunity to notice and use context and structure information. Any additional information assimilated during problem solving could affect the student's next consideration of problem similarity.

Receiving the problem solution from the teacher provides more opportunity for the student to recognize context and structure information. To the extent that the student assimilates additional information from the teacher's solution, the next consideration of problem similarity could be affected.

Finally, multiple considerations of problem similarity and solving the problem via a written solution might affect subsequent problem solving. A student could become more successful at problem solving for two reasons. First, after the entire episode of considering problems, solving problems, and receiving problem solutions, a student might finally relate problem information to existing, relevnt, useful concepts. Second, due to the entire episode, a student might develop new, relevant, useful concepts.

This study identified differences in problem-similarity recognition: (1) prior to writing a problem solution, (2) after writing a problem solution, and (3) after being presented the problem solution by the teacher. The study also determined the relation of these differences to problem-solving success, and identified any improvement in problem-solving success following multiple testing for problem-similarity recognition.

The investigation required development of two instruments to measure problem solving success, and of a third instrument to measure problem-simlarity recognition. Following their development, these instruments were used to obtain two measures of problem-solving success with multiple, intervening measures of problem-similarity recognition. The results of three one-way analyses of variance were used to interpret the relations between the problem-similarity measures and the first problem-solving success measure. Any change in problem-solving success, subsequent to multiple testing for problem-similarity recognition, was evaluated through t-test of the difference in means of dependent samples on the two problem-solving tests.

Subjects

A total of 213 chemistry students, the majority in the eleventh grade with a few in tenth or twelfth grade, in six southwest Virginia high schools, were subjects during development of the three instruments and subsequent data collection. A summary of the subject-groups is presented in Table 1. Their teachers, excepting one second-year person, each had more than five years experience teaching high school chemistry. Thirty-six of the students (Group A) used a popular traditional text. The remaining 177 students used a CHEM-Study-type text. The teacher using the traditional text stated the course included consistent formula

Table 1

Key to Subject Groups
Test-Development Groups

Group A N = 36	Solved problems during development of Problem Solving Test One.
Group B N = 30	B(1) solved Problem-Solving Test One; B(2) solved Problem-Solving Test Two
Group C N = 50	Solved Problem-Solving Tests One and Two.
Group D N = 30	Answered questions during development of Similarity Choice Test.

Experimental Group

Group E N = 27	Took Similarity Choice Test (one), Problem-Solving Test One, Similarity Choice Test (two), Similarity Choice Test (three), and Problem-Solving Test Two

application to solve problems, while the remaining teachers described a lack of emphasis on formula application in their courses.

Development of Tests

Test development included writing the three tests, submitting them to other chemistry teachers, and giving them to high school chemistry students. Copies of all tests are in the Appendix.

Problem Solving Tests One and Two

The instrument used to obtain the first measure of problem-solving success was developed in the following manner. Sixteen problems from the usual content of first semester chemistry were written by the investigator. Three other experienced chemistry teachers confirmed that all problems were typical of end-of-chapter problems. The problems were given to thirty-six students (Group A) to solve and two problems, answered correctly by every student, were discarded. The remaining fourteen problems were used for Problem Solving Test One (P.S.1).

Another instrument, Problem Solving Test Two (P.S.2), use to measure change in problem-solving success, was prepared directly from the P.S.1 problems. By changing contextual information that included numerical values and nouns such as names of elements and compounds, fourteen more problems were prepared. The contextual changes cause each P.S.2 problem to have a different answer from its corresponding P.S.1 problem. However, each P.S.2 problem has the same structure as its counterpart in P.S.1. These modified problems also appear in the Similarity Choice Test, to be described.

Comparison of P.S.1 and P.S.2

Two different comparisons of student performance on the two tests were obtained. The first comparison involved 30 students (Group B) who were randomly divided in two groups. One group of 14 took P.S.1 and another group of 16 took P.S.2. The classroom teacher administered both tests during the same class period and directed the students to show their work by writing detailed answers. The investigator scored the papers by assigning each solution zero to four points and adding the points to obtain the final score. In scoring, absence of any answer earned zero points while a correct final answer earned four points. An incomplete solution that would require only one more statement to be complete received three points. An incomplete solution requiring more than one statement to be complete, or including two correct statements, received two points. An incomplete solution with a single correct statement received one point. Samples of complete and incomplete solutions are in the Appendix.

Scores on the two tests met the assumption of homogeneity of variance, $F(15, 13) = 1.85$, $p < .01$ (Hinkle, Wiersma & Jurs, 1979, p. 229). The hypothesis of no difference in means for the two tests was retained, $t\ (28) = .56$, $p < .10$. The test statistic was computed using the Statistical System Version 4.2 for Apple II, sub-program T-TEST, equal variance model (Buhyoff, et al., 1982). Use of alpha level of 0.10 tended to reduce the probability of retaining a false hypothesis of no difference in means. The results are presented in Table 2.

The second comparison of student performance on the two tests involved 50 chemistry students (Group C) who took P.S.1 and two weeks later took P.S.2. Both P.S.1 and P.S.2 covered class material introduced a minimum of two weeks prior to the P.S.1 test day. The classroom teacher gave the tests during three class periods. During the first testing period, the teacher distributed P.S.1 and directed the students to read each problem and think about how to work it. The students wrote nothing and returned all tests to the teacher. The teacher distributed the tests the following day and directed the students to show their work on each problem by writing detailed answers. The third day, students reviewed their papers as the teacher presented

Table 2

Summary of Scores on P.S.1 and P.S.2
of Independent Samples

	P.S.1 scores	P.S.2 scores
N	14	16
Mean	23.1	20.7
S.D.	12.8	9.5

$t = .60$; c.v. = 1.70 two-tailed test;
$p < .10$; d.f. = 28

problem solutions and returned papers to the teacher. Two weeks later, students took P.S.2. They did not see the test questions prior to taking the test and were directed to write detailed answers. The classroom teacher, using the scoring procedure previously described, scored both sets of papers by assigning from zero to four points to each answer and adding the points to obtain the final score. Analysis of the data collected by this testing procedure indicated the subjects did not improve significantly in problem solving after taking P.S.1, $t\ (49) = .04$, $p < .10$ (Hinkle, Wiersma & Jurs, 1979, p. 214). The hypothesis of no difference in means of dependent samples on the two tests was retained. The results are presented in Table 3.

In summary, the analyses of the data gathered during development of P.S.1 and P.S.2 indicated that: (1) the two tests provided equivalent measures and (2) administration of P.S.2 following P.S.1 resulted in no change in problem-solving success attributable to taking P.S.1.

Similarity Choice Test

The investigator wrote the instrument used to measure problem-similarity recognition in multiple-choice format. A set of four problems, serving as multiple-choice answers, was developed for each of the problems on P.S.1. The subject would indicate which one of these four problems was

Table 3

Summary of Scores on P.S.1 and P.S.2
for Dependent Samples
N = 50

	P.S.1	P.S.2
Mean	26.3	26.3
S.D.	15.7	16.7

$t = .04$; c.v. = 1.30 one-tailed test;
$p < .10$; d.f. = 49

similar to the P.S.1 problem, according to how the subject perceived they would be worked. All four choices in a set had nearly or exactly the same number of words and order of nouns, modifiers and verb as their P.S.1 counterpart. Thus each of the four choices was similar to its P.S.1 problem in syntax. However, each problem set contained differences in context and structure (Table 4).

Similarity choice 1. One problem from each set had very nearly or exactly the same nouns and numerical values as its P.S.1 problem. This problem differed from its P.S.1 problem in the steps of its solution. For each of the fourteen sets, this problem type was similar in syntax and context to its P.S.1 problem but was different in structure as described by steps in the solution.

Similarity choice 2. A second problem in each set had nearly or exactly the same steps in the solution as its P.S.1 problem. The problem was different from its P.S.1 problem in numerical values and some of the nouns. The second type of problem in each of the fourteen sets was similar in elements of syntax and in structure to its P.S.1 problem but was different in context. The fourteen problems of this second type, similar to the fourteen P.S.1 problems in syntax and in structure, make up the previously described Problem Solving Test Two.

Table 4

Comparison of Each P.S.1 Problem with Problems in its Set of Similar Problems

Similar Syntax	Similar Context	Different Context	Similar Structure	Different Structure
--------------as compared with P.S.1 problem---------------				
choice 1	choice 1			choice 1
choice 2		choice 2	choice 2	
choice 3	choice 3		choice 3*	choice 3*
choice 4	choice 4+	choice 4+	choice 4	

*Choice 3 has structure that includes and extends structure of P.S.1 problem.

+Choice 4 has general context that includes context of P.S.1 problem and other contexts.

Similarity choice 3. A third problem in each set was similar to its P.S.1 problem in having nearly or exactly the same nouns and numerical values. The third problem type differed from the P.S.1 problem in the steps of its solution. The steps of the solution to the third problem included and extended the solution steps to its P.S.1 problem. So the third similar problem of each set and its P.S.1 problem were similar in elements of syntax and in elements of context but were different in structure.

Similarity choice 4. The fourth similar problem for each of the fourteen sets had the same solution steps as its P.S.1 problem. The two problems differed in that the fourth type used general, non-specific symbols in place of some of the numerical values and nouns in the P.S.1 problem. The fourth problem in each set was similar in elements of syntax and structure to its P.S.1 problem but differed in context.

Student response. Twenty-three chemistry students (Group D) responded to the Similarity Choice Test questions during one class period. The classroom teacher directed students to think about how to work each problem and each of the four similar problems, then to select from the four choices the one most similar to the problem in the way they would be worked. Thus the answers to the Similarity Choice Test were choices on the basis of student recognition of similarity, according to the way the student thought the problems would be worked.

The investigator observed the students while they answered the Similarity Choice questions and later interviewed three of four students chosen by their teacher. The teacher described two of the interviewed students, a girl and a boy, as poor problem solvers and the third interviewed student, a boy, as a good problem solver. The fourth student, a girl described as a good problem solver, was absent on the day of the scheduled interview. The purposes of the observations and interviews were to determine if the students could understand the test directions without asking the teacher a distracting number of questions, and if they could finish the test during one class period. All students finished the test during the fifty-five minute class period. The Similarity Choice Test subsequently used to collect data to answer the research questions for this study contained the revised directions suggested by the observations, interviews, and discussion with the classroom teacher.

Teacher reaction. Five additional experienced high school teachers classified each of the choices in the fourteen sets as either similar to or different from its comparison P.S.1 problem in syntax, context and structure. The teachers used pairs of problems other than those used in the test as models for similarities and differences. Discussion with the teachers indicated some changes in syntax and the investigator revised the appropriate problems. All five teachers classified the revised problems in the manner described earlier in this paper (Table 4).

Procedure

Following development of the instruments, 74 chemistry students (Group E, Table 1) in two high schools completed the five tests in the study. All administrations of the tests occurred under the direction of the classroom teacher during regular class periods of the fourth and fifth six-week periods. Every student present on a scheduled test day took the test, but only scores of students present on all six testing days were included in the study. The testing schedule spanned eleven successive teaching days:

Day 1: Similarity Choice Test
Day 2: Problem Solving Test One
Day 3: Similarity Choice Test
Day 4: Teacher presentation of P.S.1 solutions
Day 5: Similarity Choice Test
Day 11: Problem Solving Test Two

Students received the same directions for all three administrations of the Similarity Choice Test. Their teacher directed the students to read a problem and think about how to solve it. Then they were to read the four multiple-choice problems and think about how to solve them.

Finally each student was to select the choice most similar to the comparison problem in the way they would be solved. This process was continued until the test was completed. Students marked their answers on the test papers but wrote nothing else.

For Problem Solving Test One, students were directed to show their work on each problem by writing detailed answers. On the sixth day, students reviewed their marked P.S.1 papers as their teacher presented solutions to the problems and then returned their papers to the teacher. On the fourteenth day, students took Problem Solving Test Two after being directed to show work by writing detailed answers.

The investigator scored all tests for all students. For each Similarity Choice Test, a student's score was the sum of the points given each of the fourteen answers. The problem similar in syntax and context but different in structure earned one point if selected as the answer (Table 5). The problem similar in syntax and structure but different in context earned two points. The problem of similar syntax and context but of different though related structure earned three points. The problem similar in syntax and structure with a different, general context earned four points if selected. Different sequences of the four types of similar problems were used for the Similarity Choice Test.

Table 5

Scoring Value of Each Choice on Similarity Choice Test

Description of Choice	Scoring Value
Similar Syntax, Similar Context, Different Structure	1 point
Similar Syntax, Different (specific) Context, Similar Structure	2 points
Similar Syntax, Similar Context, Different (related) Structure	3 points
Similar Syntax, Different (general) Context, Similar Structure	4 points

The total score on Problem Solving Test One was the sum of points given each solution. No answer earned zero points while a correct answer earned four points. Partial credit of one, two or three points was given for written evidence of progress toward the answer. Problem Solving Test Two was scored in a similar manner.

Analysis

As indicated in the procedure section, every subject in Group E provided five test scores: S.C. (one), P.S.1, S.C. (two), S.C. (three), and P.S.2. According to scores on P.S.1, subjects' scores were classified in a low-problem-solving success group, a medium-problem-solving success group, and a high problem-solving success group.

The questions concerning relation of problem-solving success to problem-similarity recognition were answered using one-way analyses of variance. The hypothesis of no difference in problem-similarity recognition score for different problem-solving success groups was tested using the Statistical System Version 4.2 for Apple II, ONE WAY ANOVA, fixed effects model (Buhyoff, et al., 1982). Three F-ratios were computed for the S.C. (one), the S.C. (two), and the S.C. (three) scores. If a F-ratio exceeded the table value at the selected alpha level, the hypothesis of no difference in similarity recognition according to problem-solving success was rejected. A posteriori comparisons were made to identify the groups that differed significantly from one another, according to Gabriel's Sums of Squares Simultaneous Test Procedure, appropriate for unequal group size at the experimental alpha level (Buhyoff, et al., 1982, p. 67).

The question of change in problem-solving success following consideration of problem similarity was answered using t tests of the difference in P.S.1 and P.S.2 scores. Scores of the dependent samples were used to compute the test statistic as described by Hinkle, Wiersma & Jurs (1979, p. 214). A t value was determined for the difference in scores on the two tests for each of the problem-solving success groups. If the test statistic exceeded the table value at the selected alpha level, the hypothesis of no change in problem solving success following consideration of problem similarity was rejected for that group.

In summary, each of the 74 subjects provided problem-similarity recognition scores and problem-solving success scores. Scores were classified in three groups according to P.S.1 scores. The relations of problem-similarity recognition to problem-solving success were determined through analyses of variance. An improvement in problem solving was identified through t tests for dependent samples.

CHAPTER IV

RESULTS

The primary purposes of this study were to identify variation in problem-similarity recognition and to determine its relation to problem-solving success in high school chemistry. An additional, closely related purpose was to detect any change in problem-solving success following multiple testing with the Similarity Choice Test.

Seventy-four chemistry students (Group E, Table 1), who completed five tests of problem-solving success and problem-similarity recognition provided the data for the study. Their scores on Problem Solving Test One were the basis for classifying subjects in three problem-solving success groups. Group Low had 23 subjects with scores 0-20, Mean = 14.7. Group Medium had 30 subjects with scores 21-35, Mean = 28.3. Group High contained the remaining 21 subjects with scores 36-35, Mean = 42.6. The Grand Mean of the scores was 28.1 (Table 6). Similarity Choice Test scores for the three groups were compared, and the difference in performance according to Problem Solving Test scores was examined within each group. Correlation coefficients were computed between Problem Solving Test One scores and Similarity Choice Test scores, and Problem Solving Test Two scores.

Table 6

Problem-Solving Test One Means
and Standard Deviations

	All Subjects	Low Subjects	Medium Subjects	High Subjects
Score	0-56	0-20	21-35	36-56
N	74	23	30	21
Mean	28.1	14.7	28.3	42.6
S.D.	11.6	4.6	4.5	3.1

Problem-Solving Success and Similarity Recognition

The relation of problem-similarity recognition prior to writing a problem's solution and subsequent problem-solving success was investigated through analysis of variance of Similarity Choice (one) scores. The three groups (Low, Medium, and High) had Similarity Choice (one) means that increased in the same order as their Problem-Solving Success means. Low's mean for S.C. scores was 27.6; Medium's mean was 28.2; and High's mean was 41.9. One or more pairs of groups differed significantly, $F(2,71) = 48.27$, $p < .01$. A posteriori comparisons revealed the Low and High means were significantly different as were the Medium and High means but the Low and Medium means did not differ significantly. These results are presented in Table 7.

The relation of problem-solving success and problem-similarity recognition after writing a problem solution was determined by analysis of variance of Similarity Choice (two) score. The S.C. means were 34.3 for Low, 30.0 for Medium, and 42.7 for High. One or more pairs of these group means differed significantly, $F(2,71) = 19.02$, $p < .01$. According to a posteriori comparisons, the Low and High groups and also the Medium and High groups had significant differences. The Low mean was higher than the Medium mean,

Table 7

Summary ANOVA for Similarity Choice Test (one)

SOURCE	SS	DF	MS
Treat.	2900	2	1450
Error	2133	71	30.04
Total	5033	73	-------

F-ratio = 48.27*

TREATMENT	N	MEAN	S.D.
Low	23	27.7	3.0
Medium	30	28.2	5.4
High	21	41.9	7.3

*c. v. = 4.95;
$p < .01$; d.f. = 2, 71

but not significantly so. These results are presented in Table 8.

The relation of the problem-solving success to problem-similarity recognition following teacher presentation of solutions was interpreted through results of an analysis of variance of Similarity Choice Test (three) scores. The S.C. (three) means of the groups changed from 32.0 for Low to 29.3 for Medium to 42.8 for High. One or more pairs of groups differed significantly, $F(2,71) = 22.25$, $p < .01$. A posteriori comparisons identified groups Low and High as well as groups Medium and High as exhibiting significant difference. Low's mean was not significantly higher than Medium's mean. These results are presented in Table 9.

Improvement in Problem-Solving Success

Possible improvement in problem solving success following multiple testing with the Similarity Choice Test was examined through analysis of the Problem Solving Test score by t tests for dependent samples (Tables 10, 11, and 12). The Low means increased significantly from 14.7 for P.S.1 to 20.2 for P.S.2, $t(29) = 3.75$, $p < .05$. The means of group Medium decreased from 28.3 on P.S.1 to 26.6 on P.S.2. This change was not significant, $t(29) = 1.41$, $p < .05$. High means changed from 42.6 on P.S.1 to 45.6 on P.S.2, $t(20) = 1.99$, $< .05$. This increase in means was significant.

Table 8

Summary ANOVA for Similarity Choice Test (two)

SOURCE	SS	DF	MS
Treat.	1996	2	998.2
Error	3725	71	52.47
Total	5721	73	------

F-ratio = 19.025*

TREATMENT	N	MEAN	S.D.
Low	23	34.3	7.7
Medium	30	30.0	6.4
High	21	42.7	7.9

*c. v. = 4.95;
$p < .01$; d.f. = 2, 71

Table 9

Summary ANOVA for Similarity Choice Test (three)

SOURCE	SS	DF	MS
Treat.	2372	2	1186
Error	3785	71	53.30
Total	6157	73	------

F-ratio = 22.251*

TREATMENT	N	MEAN	S.D.
Low	23	32.0	7.6
Medium	30	29.3	6.1
High	21	42.8	8.4

*c. v. = 4.95;
$p < .01$; d.f. = 2, 71

Table 10

Summary of Scores on P.S.1 and P.S.2 for Dependent Samples* (Low)

	P.S.1	P.S.2
Mean	14.7	20.2
S.D.	4.6	7.0

N = 23

t = 3.75⁺

*Intervening Similarity Choice Tests

⁺c.v. = 1.72; one-tailed test; $p < .05$; d. f. = 22

Table 11

Summary of Scores on P.S.1 and P.S.2 for Dependent Samples* (Medium)

	P.S.1	P.S.2
Mean	28.33	26.63
S.D.	4.49	8.37

N = 30

t = 1.41⁺

*Intervening Similarity Choice Tests

⁺c.v. = 1.70; one-tailed test; $p < .05$; d. f. = 29

Table 12

Summary of Scores on P.S.1 and P.S.2 for Dependent Samples* (High)

	P.S.1	P.S.2
Mean	42.6	45.6
S.D.	3.1	8.0

N = 21

$t = 1.99^{+}$

*Intervening Similarity Choice Tests

$^{+}$c.v. = 1.75; one-tailed test; $p < .05$; d. f. = 20

Additional Analysis

In order to gain additional information from the data, correlation coefficients were computed using the Statistical System Version 4.2 for Apple II, sub-program CORRELATIONS (Buyhoff, et al., 1982). According to t tests at .05 level of significance, several of the correlation coefficients were statistically significant (Table 13). There were significant correlations for group Medium's scores for P.S.1 and S.C. (one), P.S.1 and S.C. (three), and P.S.1 and P.S.2. For group High, P.S.1 and S.C. (three) scores as well as P.S.1 and P.S.2 scores showed significant correlation.

Summary

P.S.1 scores were the basis for classifying subjects in Low, Medium, and High problem-solving success groups. Analyses of variance indicated that grous Low and High and also groups Medium and High differed significantly on the three sets of Similarity Choice Test scores. The t tests for dependent samples indicated that group Low as well as group High improved significantly in problem-solving success subsequent to multiple testing with the Similarity Choice Test. Significant correlations occurred for group Medium's

Table 13

Correlations of Problem-Solving Success Scores with other Scores

	Low	Medium	High
S.C. (one)	.34	.79*	.30
S.C. (two)	-.24	.34	.34
S.C. (three)	-.37	.55*	.59*
P.S.2	.33	.62*	.55*

*Significant; $p < .05$

scores on P.S.1 and S.C. (one) and on P.S.1 and S.C. (three) and also for group High's scores on P.S.1 and S.C. (three).

CHAPTER V

DISCUSSION

The primary purposes of this study were to identify variations in problem-similarity recognition by high school chemistry students and to examine the relation of these variations to problem-solving success. In addition, the study was designed to obtain information about possible improvement in problem solving success following multiple testing for problem-similarity recognition. These purposes led to the following research questions:

1. Do more successful problem solvers tend to recognize problem similarity according to structure (a) prior to writing a solution to the problem, (b) after writing a solution to the problem, and (c) after teacher presentation of the solution?

2. Do less successful problem solvers tend to recognize problem similarity according to context (a) prior to writing a solution to the problem, (b) after writing a solution to the problem, and (c) after teacher presentation of the solution?

3. Does problem solving success improve subsequent to multiple testing for problem-similarity recognition?

Two tests were developed and used for two measures of problem-solving success. A third test was developed and used for three intervening measures of problem-similarity recognition. Analyses of variance were conducted to examine the three sets of problem-similarity recognition scores for groups differing in initial problem-solving success. Results of these analyses consistently indicated significant differences in similarity recognition between the least and most successful problem solvers as well as between the moderately and most successful problem solvers.

Improvement in problem solving success was identified through t tests of dependent samples. Both the least and the most successful problem solvers exhibited significantly improved problem-solving scores following consideration of problem similarity. While the moderately successful problem solvers showed some decrease in score, the change was not significant.

In addition, the relation of problem-solving success to problem-similarity recognition was further described through examination of correlation coefficients.

Recognition of Problem Similarity and Problem-Solving Success

Recognition of problem similarity changed significantly across problem-solving success groups. The differences persisted for all three measures of problem similarity. The most successful problem solvers had significantly higher similarity recognition scores than the moderately successful as well as the least successful problem solvers. The high similarity recognition scores of the most successful problem solvers indicated a more frequent choice of problems similar in structure. The moderately successful and least successful problem solvers had lower similarity recognition scores. Their lower scores can be explained by a tendency to classify problems according to context similarity.

These results are consistent with Krutetskii's description of mathematics problem solvers: capable mathematics students tended to consider problems with the same structure as similar, while less capable mathematics students tended to consider problems with the same context as similar. The results of the present study are also consistent with Silver's findings: moderately strong, positive correlation between mathematics problem-solving success and sorting problems into groups according to structure, and negative correlation between problem-solving success and sorting problems into groups according to context.

Since students were directed to choose problems similar in the way they would be worked, different choices as reflected by similarity scores may indicate differences in use of problem information during problem solving. A possible explanation for the difference in problem-solving scores is that successful problem solvers, recognizing information about structure, tend to use the information during problem solving while less successful problem solvers fail to recognize or use such information. Additionally, the lower problem-solving success scores for some students may be due to recognition and use of contextual information that is insufficient for problem solution.

Correlation coefficients (Table 13) indicates additional information about the relation between problem solving and problem similarity. There were positive, moderate, significant correlations between problem-solving success scores and scores on problem-similarity recognition following teacher presentation of solutions both for the moderately successful and the most successful problem solvers. This suggests that the more successful problem solvers obtained information about structure from teacher-presented solutions. If these students were alerted to structural information during teacher-presented solutions then they could apply this information during the third Similarity Choice Test.

The moderately successful problem solvers also showed significant, positive correlation between problem-solving success and problem-similarity recognition prior to writing problem solutions. There is no clear reason for this rather strong correlation. Neither the least successful nor the most successful problem solvers had significnt correlations on the corresponding scores. Nonetheless, as problem-solving success scores increased among the moderately successful problem solvers, so did the tendency to avoid context similarity alone and to choose structure similarity. Possibly the moderately successful problem solvers, recognizing information about structure, are unable to employ the information appropriately or usefully as they construct written solutions.

As further analysis of the Similarity Choice Test data, an alternate assignment of points for the choices (Tables 4, 5) was developed. The choice with similar syntax and context but different structure was given one point. The choice with similar syntax, similar context, and related structure was given two points. The choice with similar syntax, general context, and similar structure was given three points. The choice with similar syntax, similar context, and similar structure was given four points.

The alternate coding, displayed in Table 14, is based on three assumptions. First, the structure of the problem that includes and extends the structure of its comparison problem is more different from than similar to the structure of its comparison problem. Second, the problem choice

Table 14

Alternate Scoring Value of Each
Choice on Similarity Choice Test

Decription of Choice	Scoring Value
Similar Syntax, Similar Context, Different Structure	1 point
Similar Syntax, Similar Context, Different (related) Structure	2 points
Similar Syntax, Different (general) Context, Similar Structure	3 points
Similar Syntax, Different (specific) Context, Similar Structure	4 points

having a general context and similar structure is less similar to its comparison problem in structure than the problem choice with different context and similar structure. Third, the contextually different and structurally similar problem choice is most different in context while being most similar in structure to its comparison problem.

The three sets of recoded Similarity Choice Test scores, generated by the alternate coding, were examined by analysis of variance. The results are displayed in Tables 15, 16, and 17. The three problem-solving success groups (Low, Medium, and High) had recoded Similarity Choice Test (one) means that increased in the same order as their original Similarity Choice Test (one) means (Table 7). However, the recoded scores' means were higher than the original scores' means:

group Low: original mean = 27.7, recoded mean = 34.9

group Medium: original mean = 28.2, recoded mean = 44.4

group High: original mean = 41.9, recoded mean = 47.5

One or more pairs of (recoded) means differed significantly, $F(2,71) = 22.86$, $p < .01$. A posteriori comparisons indicated groups Low and Medium as well as groups Low and High differed significantly.

The three problem-solving success groups had recoded means on Similarity Choice Tests (two) and (three) that increased in order from group Low to group Medium to group

Table 15

Summary ANOVA for Similarity Choice Test (one)

SOURCE	SS	DF	MS
Treat.	1960	2	980
Error	3044	71	42.9
Total	5004	73	-------

F-ratio = 22.86*

TREATMENT	N	MEAN	S.D.
Low	23	34.9	6.2
Medium	30	44.4	8.0
High	21	47.5	4.2

*c. v. = 4.95;
$p < .01$; d.f. = 2, 71

Table 16

Summary ANOVA for Similarity Choice Test (two)
Alternate Scoring

SOURCE	SS	DF	MS
Treat.	269	2	134.3
Error	2625	71	37.0
Total	2893	73	------

F-ratio = 3.63*

TREATMENT	N	MEAN	S.D.
Low	23	38.6	6.0
Medium	30	42.4	6.9
High	31	43	4.7

*c. v. = 4.95;
p < .01; d.f. = 2, 71

Table 17

Summary ANOVA for Similarity Choice Test (three)
Alternate Scoring

SOURCE	SS	DF	MS
Treat.	193	2	96.8
Error	3036	71	42.8
Total	3229	73	------

F-ratio = 2.25*

TREATMENT	N	MEAN	S.D.
Low	23	36.7	7.4
Medium	30	39.4	5.7
High	21	40.8	6.7

*c. v. = 4.95;
$p < .01$; d.f. = 2, 71

High. The increase in (recoded) Similarity Choice Test (two) means was not significant, $F(2,71) = 3.63$, $p < .01$. Nor was the increase in means for (recoded) Similarity Choice Test (three) significant, $F(2,71) = 2.25$, $p < .01$.

The less successful problem solvers exhibited parallel trends in initial problem-similarity recognition and problem-solving success. The students with lowest P.S.1 score had the lowest (recoded) S.C. (one) scores, while the students with medium P.S.1 scores had higher (recoded) S.C. (one) scores.

This suggests that the least successful problem-solvers tend to focus on context similarity, even a general expression of context, rather than structure similarity. As these students fail to notice structure similarity, they may not use the important structure information in the problem while attempting to solve it.

The moderately successful problem solvers may focus on similarity in the general expression of structure and in the specific instance of similar structure. However, the most successful problem solvers also focus on similarity in the general expression and the specific instance of similar structure. The moderately successful problem solvers may not use the important structure information as well as the most successful problem solvers, even though both groups tend to recognize similar structure.

An interesting result of the additional analysis is the indication that the subjects, regardless of performance on P.S.1, did not differ from one another in problem-similarity recognition after writing solutions to P.S.1. Nor did they differ from one another in similarity recognition after receiving the solutions to P.S.1. This suggests that problem-similarity recognition is readily influenced by routine instructional activities: solving problems and receiving their solutions. However, if such typical activities do influence all students' similarity recognition uniformly, the influence does not persist. The subjects' response to S.C.(one) depended on their previous experiences in chemistry, including solving problems and receiving solutions. Any uniformity in similarity recogniton after previous occasions of solving problems and receiving solutions disappeared. The subjects differed from one another in their initial (recoded) Similariity Choice Test scores, and differed according to subsequent problem-solving success groups.

Comparison of the analyses of the original Similarity Choice Test scores and the recoded scores indicates:

1. Problem-solving success groups Low and Medium did not differ in original S.C.(one) scores. Groups Medium and High did not differ in recoded S.C.(one) scores.

2. Problem-solving success groups differed in original S.C.(two) scores and also in original S.C.(three) scores. Problem-solving success groups did not differ in recoded S.C.(two) or recoded S.C.(three) scores.

According to the original Similarity Choice Test scores, students differ from one another in their recognition of problem similarity. Students exhibit the differences prior to solving problems, after solving problems, and after receiving the solutions. Thus, instruction to modify problem-similarity recogniton and affect problem-solving success must be different from such typical instructional practices.

According to the recoded Similarity Choice scores, students differ from one another in problem-similarity recognition prior to solving the problems. Following the typical instructional events of solving problems and receiving the solution, students no longer differ from one another in problem-similarity recognition. However, this uniformity in student performance does not persist, nor is its potential, positive effect on problem-solving success realized. Existing instructional practices may lead to instruction that modifies and then maintains problem-similarity recognition.

Additional studies can reveal how students rank the similarities in the four context variations and the similarities in the four structure variations used in this study.

Improvement in Problem-Solving Success

Speculation about the process of considering problem similarity gives rise to the question of its effect on problem-solving success. The process of choosing among several similar problems would allow the student to consider and identify information in the problem for the purpose of solving it. The second problem-solving success measure provided information about the effect of several opportunities for problem-similarity recognition on problem-solving success.

Development of the tests to measure problem-solving success included giving both tests to a sample of high school chemistry students (Group C). Results of the analysis of test scores indicated the sample did not improve significantly in performance on P.S.2. However, of the students (Group E) who responded on three occasions to the Similarity Choice Test, the majority did exhibit significant improvement on P.S.2. Only those students classified as moderately successful problem solvers showed a non-significant decrease in problem-solving success. The other students, least successful as well as most successful, showed significant improvement in problem solving.

As regression to the mean is a possible contributing factor in the gain in scores for group Low, the scores of group C were reexamined. The scores of the group C subjects with P.S. scores from 0-20 were examined by means of t test for dependent samples. Analysis of the data indicated the low-scoring subjects had no significant improvement in the test scores, $t\ (21) = 1.18$, $p < .05$ (Hinkle, et al., 1979). The results are displayed in Table 18.

Krutetskii described the average mathematics students who had solved numerous examples of problems with similar structure as gradually tending to generalize the problems' solution. In contrast, Krutetskii described the least capable students as generalizing similar solutions infrequently or not at all. To the extent that generalization of solution implies problem-solving success, the improvement in problem-solving success in this study may not be consistent with Krutetskii's description of unsuccessful mathematics problem solvers. The least successful problem solvers in this study did improve in problem-solving success. Before any student can generalize a successful problem solution, the student requires experience at developing successful problem solutions. Perhaps the least successful chemistry problem solvers, having considered problem similarity, only benefited sufficiently to solve individual problems more successfully.

Table 18

Summary of Scores on P.S.1 and P.S.2
for Dependent Samples
P.S.1 Scores < = 20
N = 22

	P.S.1	P.S.2
Mean	11.54	13.63
S.D.	5.65	11.09

$t = 1.07$; c.v. = 1.72 one-tailed test;
$p > .5$; d.f. = 21

This study includes no evidence for or against their ability to generalize solutions.

A possible explanation for improved student performance on the second problem-solving test involves scores on the Similarity Choice Test. All three Similarity Choice Test scores for the least successful problem solvers were significantly lower than the scores for the most successful problem solvers. This suggests that the nature of the similarity choice might not be the only factor affecting problem-solving success. Rather, the process of making the similarity choice could be responsible for the improved problem solving. Perhaps the least successful problem solvers benefited from similarity considerations due to spending more time thinking about the problems and thinking about them in varied ways. The most successful problem solvers might have benefited for similar reasons. In addition, tendency to recognize structural similarity in problems would given the most successful problem solvers helpful, structural information to use during problem solving.

The moderately successful problem solver did not change significantly in problem-solving score. Obviously the additional time spent considering the problems did not result in improvement for these students. A possible explanation for their stable performance lies in their similarity choice scores. All three Similarity Choice Test scores for the moderately successful problem solvers, while statistically equivalent to the least successful problem solvers' scores, were significantly lower than their more successful counterparts. This indicates the moderately successful problem solvers were not choosing problems related in structure to the extent the most successful students were. Apparently the additional time spent considering problem similarity gave these moderately successful problem solvers no new, helpful information. And their tendency to recognize structure was not strong enough to obtain additional, useful information for solving problems similar in structure.

Conclusions

Based on analyses of the performance of subjects in this study, the conclusions regarding problem-solving success and problem-similarity recognition are:

1. The more successful problem solvers tended to recognize problem similarity according to structure: (a) prior to writing a solution to the problem, (b) after writing a solution to the problem, and (c) after teacher presentation of the solution.

2. The less successful problem solvers tended to recognize problem similarity according to context: (a)

prior to writing a solution to the problem, (b) after writing a solution to the problem, and (c) after teacher presentation of the solution.

3. Subsequent to multiple testing for problem-similarity recognition, the most successful and the least successful problem solvers improved in problem-solving success.

Recommendations

These conclusions and information from this study suggest several recommendations involving instruction and additional studies.

1. The most important results of this study are the identification of variations in students' problem-similarity recognition and of the relation of problem-similarity recognition to problem-solving success. Differences in problem-solving similarity recognition, as well as differences in problem-solving success, indicate differences in student learning during the study of chemistry. As similarity recognition differences and problem-solving success differences are directly related to course content, they may reasonably be considered during instruction. (Student differences such as reading performance variations or mathematics knowledge variations would not be as readily considered during chemistry instruction.)

Instructional activities involving problem similarities include the following: (a) explicit discussion of problems that include mutually exclusive examples of context similarity and structure similarity, (b) student generation of companion problems similar in structure or in context, (c) use of problems related in that one structure includes and extends another structure, (d) identification of problems similar either in context or in structure from a list of problems.

In addition to a possible, direct, positive effect due to explicit instruction involving problem similarity, there may also be a positive effect from a more subtle source. Consideration of problem similarity gives the teacher a novel, plausible, readily available attribute of chemistry problem solving to manipulate during instruction. A fresh dimension to instruction allows the teacher to plan with a renewed interest that can have a positive effect on students.

2. Additional studies can reveal how students rank the similarities in the four context variations and the similarities in the four structure variations used in this study. Students could rank the choices in a given set according to context similarity, with all choices having variations in context but similar structures. Or subjects could rank the choices in a set according to structure

similarity, with all choices having similar contexts but variations in structures.

3. More can be learned about problem-similarity recognition and problem-solving success by studying student performance on applied problems in other science content areas. If variation in problem-similarity recognition persists in science content areas other than chemistry, then explicit instruction involving similarity recognition in those courses may be of benefit to the students. As a traditional site of problem-solving difficulty, high school physics with its problem-rich content seems especially appropriate for additional studies.

4. Another dimension to improved problem solving could be examined by incorporating explicit problem similarity consideration in eighth or ninth grade physical science. Its possible effect at that grade level could be determined, and its subsequent effect during high school chemistry and physics could be examined.

5. Responses of students to more differentiated, individualized instruction involving problem similarity merits attention. The present study indicates that the traditional practice of giving students several examples with the same structure but different elements of context could be least helpful to students who most need help. If the least successful tend to establish similarity patterns

according to context, they may benefit from deliberate study of context similarity through realizing the limits of its usefulness. Additionally, correlation coefficients for the least successful problem solvers in this study display a shift in the direction of decreasing context choice and increasing structure choice on the three testings for similarity recognition. While these correlations were not significant, it would be a mistake to dismiss this occurrence of change in correlation. If other less successful problem solvers persist in tending to shift their recognition of problem similarity toward structure, they may be able to learn to use the structure similarity.

More successful problem solvers in this study tended to recognize problem similarity according to structure. If such students are explicitly directed to seek structure similarity, they may become even more conscious of the similarity most helpful in solving problems.

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APPENDIX A

1. Scores for Developmental Comparisons of Problem Solving Tests One and Two
2. Scores as Data for Research Questions: Similarity Choice Test (one), Problem Solving Test One, Similarity Choice Test (two), Problem Solving Test Two

Scores for Developmental Comparison of
Problem Solving Tests One and Two,
Independent Samples

VAR:	P.S.	SCOR
01:	1	15
02:	1	17
03:	1	34
04:	1	46
05:	1	41
06:	1	15
07:	1	0
08:	1	19
09:	1	7
010:	1	34
011:	1	24
012:	1	26
013:	1	29
014:	1	17
015:	2	15
016:	2	33
017:	2	7
018:	2	22

VAR:	P.S.	SCOR
019:	2	35
020:	2	16
021:	2	17
022:	2	26
023:	2	13
024:	2	28
025:	2	32
026:	2	17
027:	2	31
028:	2	24
029:	2	7
030:	2	8

Scores for Developmental Comparison of Problem Solving Tests One and Two, Dependent Samples

VAR:	PS1	PS2
01:	16	44
02:	4	20
03:	4	0
04:	12	8
05:	32	48
06:	36	32
07:	23	40
08:	20	20
09:	39	36
010:	12	12
011:	52	48
012:	28	28
013:	16	12
014:	52	48
015:	52	48
016:	12	20
017:	27	48
018:	8	16
019:	32	24
020:	16	12
021:	8	4
022:	44	40
023:	52	40
024:	44	40
025:	44	44
026:	12	8
027:	24	0
028:	40	40
029:	4	0
030:	40	32
031:	16	20
032:	0	0
033:	7	0
034:	15	12
035:	12	8
036:	24	12
037:	36	52
038:	52	52
039:	20	12
040:	12	16
041:	44	44
042:	20	36
043:	26	16
044:	40	20
045:	52	44
046:	8	20
047:	24	48
048:	24	20
049:	40	32
050:	40	40

Scores as Data for Research Questions

VAR:	PS2	PS1	SC1
01:	12	18	28
02:	39	33	31
03:	20	25	24
04:	47	45	39
05:	56	46	43
06:	20	20	28
07:	50	46	48
08:	28	29	31
09:	12	17	21
010:	54	43	31
011:	55	44	54
012:	6	12	24
013:	25	27	27
014:	12	16	30
015:	9	22	22
016:	16	16	24
017:	30	33	34
018:	51	46	34

VAR:	CODE	SC2	SC3
01:	111	21	20
02:	222	34	32
03:	222	26	25
04:	333	36	40
05:	333	39	44
06:	111	37	30
07:	333	34	38
08:	222	36	29
09:	111	28	25
010:	333	42	33
011:	333	54	54
012:	111	34	22
013:	222	28	27
014:	111	24	32
015:	222	42	40
016:	111	28	26
017:	222	31	33
018:	333	48	52

VAR:	PS2	PS1	SC1
019:	24	26	28
020:	17	4	25
021:	26	14	26
022:	40	47	36
023:	39	34	36
024:	26	20	35
025:	55	40	33
026:	18	21	28
027:	26	23	23
028:	34	43	45
029:	36	42	41
030:	21	14	29
031:	22	33	31
032:	33	35	36
033:	35	40	44
034:	41	39	32
035:	49	33	25
036:	30	22	22

VAR:	CODE	SC2	SC3
019:	222	28	26
020:	111	35	34
021:	111	32	27
022:	333	43	46
023:	222	31	34
024:	111	44	40
025:	333	44	40
026:	222	27	30
027:	222	24	28
028:	333	45	43
029:	333	40	40
030:	111	30	31
031:	222	25	27
032:	222	32	34
033:	333	33	30
034:	333	36	34
035:	222	31	30
036:	222	26	20

VAR:	PS2	PS1	SC1
037:	10	15	25
038:	22	20	30
039:	55	47	49
040:	49	43	46
041:	24	14	27
042:	31	28	27
043:	40	41	46
044:	35	26	31
045:	24	9	28
046:	30	17	30
047:	20	27	25
048:	46	41	52
049:	23	26	25
050:	14	24	21
051:	31	20	30
052:	25	23	20
053:	41	39	48
054:	56	46	50
VAR:	PS2	PS1	SC1
055:	21	23	21
056:	32	39	31
057:	39	33	33
058:	40	36	34
059:	44	42	43
060:	20	30	27
061:	25	18	28
062:	30	20	29
063:	26	33	30
064:	24	26	24
065:	28	16	32
066:	29	32	39
067:	30	33	34
068:	15	6	30
069:	28	32	39
070:	23	9	26
071:	15	9	26
072:	27	34	30
VAR:	PS2	PS1	SC1
073:	15	24	23
074:	20	14	25

VAR:	CODE	SC2	SC3
037:	111	28	28
038:	111	45	32
039:	333	52	56
040:	333	47	44
041:	111	43	40
042:	222	28	29
043:	333	48	48
044:	222	31	29
045:	111	40	40
046:	111	36	32
047:	222	25	22
048:	333	49	50
049:	222	30	25
050:	222	21	24
051:	111	30	32
052:	222	20	20
053:	333	56	46
054:	333	53	56
VAR:	CODE	SC2	SC3
055:	222	21	23
056:	333	29	27
057:	222	32	32
058:	333	31	32
059:	333	37	45
060:	222	28	28
061:	111	28	26
062:	111	28	26
063:	222	31	32
064:	222	24	26
065:	111	34	30
066:	222	49	48
067:	222	31	36
068:	111	36	39
069:	222	38	37
070:	111	54	52
071:	111	32	28
072:	222	30	31
VAR:	CODE	SC2	SC3
073:	222	40	21
074:	111	41	45

APPENDIX B

1. Developmental Directions and Problems for Problem Solving Test One
2. Developmental Directions and Problems for Similarity Choice Test.

Developmental Directions and Problems for Problem Solving Test One

1. Put your name on the back of this page.
2. Put your answers on your own paper.
3. SHOW YOUR WORK.

1. How many moles of NaCl will form from 5 moles of NaI?
   Cl_2 + 2 NaI --- 2 NaCl + I_2
2. How many moles are 6 liters of fluorine at 1.0 atmosphere and 273 Kelvins?
3. The charge of one mole of H^+ ions is 9.6 x 10^4 coulombs. What is the charge of one proton?
4. The mass of an atom of chlorine is 37 a.m.u. How many protons has the atom?
5. How many moles are 3 liters of oxygen at 1.0 atmosphere and 350 Kelvins?
6. What is the density of 88.75 grams of a metal sample of volume 35.5 milliliters?
7. How many moles of NaCl will form from 3 moles of Cl_2?
   Cl_2 + 2 NaI --- 2 NaCl + I_2
8. What is the molarity of 1.5 liters of solution containing 4 moles of sodium chloride?

9. How many moles are 7 liters of hydrogen at 1.5 atmospheres and 273 Kelvins?

10. What is the volume in liters of 1,231 milliliters of a liquid?

11. How many moles are 5 liters of nitrogen at 2.5 atmospheres and 375 Kelvins?

12. Molar Heat of Melting = 1.4 kcal/mole   Specific Heat = 1.0 cal/g·degree C
How much heat must be removed to freeze 15 grams of zero degree C water?

13. How many moles are required to prepare 1.5 liters of 2.5 M solution of potassium nitrate?

14. What is the empirical formula of a compound containing 1.0 mole of sulfur for every 2.0 moles of oxygen?

15. How many moles of lithium oxide, Li_2O, can be formed from 3.6 moles of lithium?

16. $c = 3.0 \times 10^{10}$ cm/sec $h = 9.52 \times 10^{-14}$ kcal·sec/mole
What is the frequency of radiation of wavelength 1.2×10^{-6} cm?

Developmental Directions and Problems for
Similarity Choice Test

DIRECTIONS:

1. Put your name on the back of this sheet.
2. Think about how you would solve each of the problems.
3. Then think about how you would solve the A, B, C, and D choices for each of the problems.
4. Then think about which of the four choices (A, B, C, D) you would judge to be most similar to the problem in its solution.
5. Mark your answer on the test paper.

1. Cl_2 + 2 NaI yield 2 NaCl + I_2

   How many moles of NaCl will form from 5 moles of NaI?

   A. Cl_2 + 2 NaI yield 2 NaCl + I_2

      How many grams of NaCl will form from 5 moles of NaI?

   B. X_a + YZ yield a YX + Z_a

      How many moles of YX will form from M moles of YZ?

   C. Cl_2 + 2 NaI yield 2 NaCl + I_2

      How many moles of NaCl will 5 grams of NaCl be?

   D. F_2 + 2 KBr yield 2 KF + Br_2

      How many moles of KF will form from 3 moles of KBr?

2. The charge of one mole of H^+ ions is 9.6×10^4 coulombs. What is the charge of one proton?

   A. The charge of M moles of Ion^+ is C coulombs. What is the charge of one proton?

   B. The charge of one mole of H^+ ions is 9.6×10^4 coulombs. What is the formula for one proton?

   C. The charge of one mole of Li^+ ions is 9.6×10^4 coulombs. What is the charge of one proton?

   D. The charge of 0.5 moles of F^- ions is 4.8×10^4 coulombs. What is the charge of one electron?

3. How many moles are 6 liters of fluorine at 1.0 atmosphere, 273 Kelvins?

   A. How many moles are 7 liters of oxygen at 1.0 atmosphere, 273 Kelvins?

   B. How many moles are 6 grams of fluorine at 1.0 atmosphere, 273 Kelvins?

   C. How many moles are L liters of G gas at 1.0 atmosphere, 273 Kelvins?

   D. How many grams are 6 liters of fluorine at 1.0 atmosphere, 273 Kelvins?

4. What is the molarity of 4 moles of sodium chloride in 1.5 liters of solution?

   A. What is the molarity of 40 grams of sodium chloride in 1.5 liters of solution?

   B. What is the molarity of M moles of C chemical in L liters of solution?

   C. How many milliliters are 4 moles of sodium chloride in 1.5 liters of solution?

   D. What is the molarity of 7 moles of potassium fluoride in 2.5 liters of solution?

5. The mass of an atom of chlorine is 37 a.m.u. How many protons has the atom?
   A. The mass of an atom of nitrogen is 15 a.m.u. How many protons has the atom?
   B. The mass of an atom of chlorine is 37 a.m.u. What is the symbol for the atom?
   C. The mass of an atom of element A is N a.m.u. How many protons has the atom?
   D. The mass of an atom of chlorine is 37 a.m.u. How many neutrons has the atom?

6. How many moles are 5 liters of nitrogen at 2.5 atmospheres, 375 Kelvins?
   A. How many grams are 5 liters of nitrogen at 2.5 atmospheres, 375 Kelvins?
   B. How many moles are 3 liters of fluorine at 2.0 atmospheres, 350 Kelvins?
   C. How many moles are 5 grams of nitrogen at 2.5 atmospheres, 375 Kelvins?
   D. How many moles are L liters of G gas at P atmospheres, T Kelvins?

7. How many moles are 3 liters of oxygen at 1.0 atmosphere, 225 Kelvins?
   A. How many grams are 3 liters of oxygen at 1.0 atmosphere, 225 Kelvins?
   B. How many moles are L liters of G gas at 1.0 atmosphere, T Kelvins?
   C. How many moles are 3 grams of oxygen at 1.0 atmosphere, 225 Kelvins?
   D. How many moles are 5 liters of nitrogen at 1.0 atmosphere, 200 Kelvins?

8.

Molar Heat of Melting (kcal/mole)	Specific Heat (cal/g·degree C)	Substance
6.8	0.21	sodium chloride
1.4	1.0	water

How much heat must be removed to freeze 15 grams of zero degree water?
   A. How much heat must be removed to freeze 6.0 grams of sodium chloride, no temperature change?
   B. How much heat must be removed to freeze G grams of element A, no temperature change?
   C. How much heat must be removed to freeze 15 grams of 15 degrees water?
   D. How much heat must be removed to cool 15 grams of water by one degree C?

9. How many moles of potassium nitrate are required to prepare 1.5 liters of 2.5 M solution?

   A. How many grams of potassium nitrate are required to prepare 1.5 liters of 2.5 M solution?

   B. How many milliliters are 1.5 liters of 2.5 M solution of potassium nitrate?

   C. How many moles of sodium chloride are required to prepare 2.4 liters of 3.4 molar solution?

   D. How many moles of chemical are required to prepare L liters of M molar solution?

10. How many moles are 7 liters of hydrogen at 1.5 atmospheres, 273 Kelvins?

   A. How many moles are 7 grams of hydrogen at 1.5 atmospheres, 273 Kelvins?

   B. How many moles are L liters of G gas at P atmospheres, 273 Kelvins?

   C. How many grams are 7 liters of hydrogen at 1.5 atmospheres, 273 Kelvins?

   D. How many moles are 5 liters of oxygen at 2.0 atmospheres, 273 Kelvins?

11. What is the empirical formula of a substance containing 1.0 mole of sulfur for every 2.0 moles of oxygen?

   A. What is the total mass of a substance containing 1.0 gram of sulfur and 2.0 grams of oxygen?

   B. What is the empirical formula of a substance containing 1.0 gram of sulfur for every 1.0 gram of oxygen?

   C. What is the empirical formula of a substance containing 1.0 mole of aluminum for every 3.0 moles of fluorine?

   D. What is the empirical formula of a substance containing X moles of element A for every Y moles of element B?

12. Cl_2 + 2 NaI yield 2 NaCl + I_2

   How many moles of NaCl will form from 3 moles of Cl_2?

   A. Cl_2 + 2 NaI yield 2 NaCl + I_2

      How many moles of NaCl will 3 grams of NaCl be?

   B. X_a + a YZ yield a YX + Z_a

      How many moles of YX will form from M moles of X_a?

   C. F_2 + 2 KBr yield 2 KF + Br_2

      How many moles of KF will form from 5 moles of F_2?

   D. Cl_2 + 2 NaI yield 2 NaCl + I_2

      How many grams of NaCl will form from 3 moles of Cl_2?

13. How many moles of lithium oxide, Li_2O, can be formed from 3.6 moles of lithium?

    A. How many grams of lithium oxide, Li_2O, can be formed from 3.6 moles of lithium?

    B. How many moles of calcium carbide, CaC_2, can be formed from 5.8 moles of carbon?

    C. How many grams of lithium oxide, Li_2O, contain 3.6 grams of lithium and 4.2 grams of oxygen.

    D. How many moles of X_aY_b can be formed from $\underline{M}$ moles of X?

14. $c = 3.0 \times 10^{10}$ cm/sec $\qquad h = 9.52 \times 10^{-14}$ kcal·sec/mole

    What is the frequency of radiation of wavelength 1.2×10^{-6} cm?

    A. What is the frequency of radiation of wavelength $\underline{X}$ cm?

    B. What is the frequency of radiation of wavelength 5.8×10^{-9} cm?

    C. What is the energy of radiation of wavelength 1.2×10^{-6} cm?

    D. What is the velocity of radiation of wavelength 1.2×10^{-6} cm?

APPENDIX C

1. Problem Solving Test One
2. Problem Solving Test Two
3. Similarity Choice Test

Problem Solving Test One

STUDENT NAME:

1. Cl_2 + 2 NaI yields 2 NaCl + I_2
   How many moles of NaCl will form from 5 moles of NaI?

2. The charge of one mole of H^{+1} ions is 9.6×10^4 coulombs. What is the charge of one proton?

3. How many moles are 6 liters of fluorine at 1.0 atmosphere, 273 Kelvins?

4. What is the molarity of 1.5 liters of solution containing 4 moles of sodium chloride?

5. The mass of an atom of chlorine is 37 a.m.u. How many protons has the atom?

6. How many moles are 5 liters of nitrogen at 2.5 atmospheres, 375 Kelvins?

7. How many moles are 3 liters of oxygen at 1.0 atmosphere, 225 Kelvins?

8. Molar Heat of Melting = 1.4 kcal/mole   Specific Heat = 1.0 cal/g
   Melting Temperature = zero degrees C
   How much heat must be removed to freeze 15 grams of water at zero degrees C?

9. How many moles of potassium nitrate are required to prepare 1.5 liters of 2.5 molar solution?

10. How many moles are 7 liters of hydrogen at 1.5 atmospheres, 273 Kelvins?

11. What is the empirical formula of a substance containing 1.0 mole of sulfur for every 2.0 moles of oxygen?

12. Cl_2 + 2 NaI yields 2 NaCl + I_2
    How many moles of NaCl will form from 3 moles of Cl_2?

13. How many moles of lithium oxide, Li_2O, can be formed from 3.6 moles of lithium?

14. $c = 3.0 \times 10^{10}$ cm/sec $h = 9.52 \times 10^{-14}$ kcal•sec/mole
What is the frequency of radiation of wavelength 1.2×10^{-6} cm?

Problem Solving Test Two

STUDENT NAME:

1. F_2 + 2 KBr yields 2 KF + Br_2

   How many moles of KF will form from 3 moles of KBr?

2. The charge of 0.5 mole of F^{-1} ions is 4.8 x 10^4 coulombs. What is the charge of one electron?

3. How many moles are 7 liters of oxygen at 1.0 atmosphere, 273 Kelvins?

4. What is the molarity of 2.5 liters of solution containing 7 moles of potassium fluoride?

5. The mass of an atom of nitrogen is 15 a.m.u. How many protons has the atom?

6. How many moles are 3 liters of fluorine at 2.0 atmospheres, 350 Kelvins?

7. How many moles are 5 liters of nitrogen at 1.0 atmosphere, 200 Kelvins?

8. Molar Heat of Melting = 6.8 kcal/mole   Specific Heat = 0.21 cal/g degree

   Melting Temperature = 800 degrees C

   How much heat must be removed to freeze 6 grams of sodium chloride at 800 degrees C?

9. How many moles of sodium chloride are required to prepare 2.4 liters of 3.4 molar solution?

10. How many moles are 5 liters of oxygen at 2.0 atmospheres, 273 Kelvins?

11. What is the empirical formula of a substance containing 1.0 mole of aluminum for every 3.0 moles of fluorine?

12. F_2 + 2 KBr yields 2 KF + Br_2
How many moles of KF will form from 5 moles of F_2?

13. How many moles of calcium carbide, CaC_2, can be formed from 5.8 moles of carbon?

14. $c = 3.0 \times 10^{10}$ cm/sec $\quad$ $h = 9.52 \times 10^{-14}$ kcal·sec/mole
What is the frequency of radiation of wavelength 5.8×10^{-9} cm?

Similarity Choice Test

STUDY THE PROBLEM. THINK ABOUT HOW YOU WOULD WORK IT.

THEN STUDY EACH CHOICE. THINK ABOUT HOW YOU WOULD WORK THEM.

MARK THE CHOICE MOST SIMILAR TO THE PROBLEM IN THE WAY IT IS WORKED.

STUDENT NAME:

1. Cl_2 + 2 NaI yields 2 NaCl + I_2

   How many moles of NaCl will form from 5 moles of NaI?

   A. Cl_2 + 2 NaI yields 2 NaCl + I_2

      How many grams of NaCl will form from 5 moles of NaI?

   B. X_a + a YZ yields a YX + Z_a

      How many moles of YX will form from M moles of YZ?

   C. Cl_2 + 2 NaI yields 2 NaCl + I_2

      How many moles of NaCl will 5 grams of NaCl be?

   D. F_2 + 2 KBr yields 2 KF + Br_2

      How many moles of KF will form from 3 moles of KBr?

2. The charge of one mole of H^{+1} ions is 9.6 x 10^4 coulombs. What is the charge of one proton?

   A. The charge of M moles of Ion^{+1} is C coulombs. What is the charge of one proton?

   B. The charge of one mole of protons is 9.6 x 10^4 coulombs. What is the formula of a proton?

   C. The charge of one mole of Li^{+1} ions is 9.6 x 10^4 coulombs. What is the charge of one proton?

   D. The charge of 0.5 moles of F^{-1} ions is 4.8 x 10^4 coulombs. What is the charge of one electron?

3. How many moles are 6 liters of fluorine at 1.0 atmosphere, 273 Kelvins?

   A. How many moles are 7 liters of oxygen at 1.0 atmosphere, 273 Kelvins?

   B. How many moles are 6 grams of fluorine at 1.0 atmosphere, 273 Kelvins?

   C. How many moles are L liters of G gas at 1.0 atmosphere, 273 Kelvins?

   D. How many grams are 6 liters of fluorine at 1.0 atmosphere, 273 Kelvins?

4. What is the molarity of 1.5 liters of solution containing 4 moles of sodium chloride?
   A. What is the molarity of 1.5 liters of solution containing 40 grams sodium chloride?
   B. What is the molarity of L liters of solution containing M moles of C chemical?
   C. How many milliliters are 1.5 liters of solution containing 4 moles of sodium chloride?
   D. What is the molarity of 2.5 liters of solution containing 7 moles of potassium fluoride?

5. The mass of an atom of chlorine is 37 a.m.u. How many protons has the atom?
   A. The mass of an atom of nitrogen is 15 a.m.u. How many protons has the atom?
   B. The mass of an atom of chlorine is 37 a.m.u. What is the symbol for the atom?
   C. The mass of an atom of element A is N a.m.u. How many protons has the atom?
   D. The mass of an atom of chlorine is 37 a.m.u. How many neutrons has the atom?

6. How many moles are 5 liters of nitrogen at 2.5 atmospheres, 375 Kelvins?
   A. How many moles are 3 liters of fluorine at 2.0 atmospheres, 350 Kelvins?
   B. How many moles are L liters of G gas at P atmospheres, T Kelvins?
   C. How many moles are 5 grams of nitrogen at 2.5 atmospheres, 375 Kelvins?
   D. How many grams are 5 liters of nitrogen at 2.5 atmospheres, 375 Kelvins?

7. How many moles are 3 liters of oxygen at 1.0 atmosphere, 225 Kelvins?
   A. How many grams are 3 liters of oxygen at 1.0 atmosphere, 225 Kelvins?
   B. How many moles are L liters of G gas at 1.0 atmosphere, T Kelvins?
   C. How many moles are 3 grams of oxygen at 1.0 atmosphere, 225 Kelvins?
   D. How many moles are 5 liters of nitrogen at 1.0 atmosphere, 200 Kelvins?

8. How many moles of potassium nitrate are required to prepare 1.5 liters of 2.5 molar solution?
   A. How many grams of potassium nitrate are required to prepare 1.5 liters of 2.5 molar solution?
   B. How many milliliters are 1.5 liters of 2.5 molar solution of potassium nitrate?
   C. How many moles of sodium chloride are required to prepare 2.4 liters of 3.4 molar solution?
   D. How many moles of chemical are required to prepare L liters of M molar solution?

9. How many moles of lithium oxide, Li_2O, can be formed from 3.6 moles of lithium?
   A. How many grams of lithium oxide, Li_2O, can be formed from 3.6 moles of lithium?
   B. How many moles of calcium carbide, CaC_2, can be formed from 5.8 moles of carbon?
   C. How many grams of lithium oxide, Li_2O, contain 3.6 grams of lithium and 4.2 grams of oxygen?
   D. How many moles of X_aY_b can be formed from M moles of X?

10. How many moles are 7 liters of hydrogen at 1.5 atmospheres, 273 Kelvins?
   A. How many moles are 7 grams of hydrogen at 1.5 atmospheres, 273 Kelvins?
   B. How many moles are L liters of G gas at P atmospheres, 273 Kelvins?
   C. How many grams are 7 liters of hydrogen at 1.5 atmospheres, 273 Kelvins?
   D. How many moles are 5 liters of oxygen at 2.0 atmospheres, 273 Kelvins?

11. What is the empirical formula of a substance containing 1.0 mole of sulfur for every 2.0 moles of oxygen?
   A. What is the total mass of a substance containing 1.0 gram of sulfur and 2.0 grams of oxygen?
   B. What is the empirical formula of a substance containing 1.0 gram of sulfur for every 1.0 gram of oxygen?
   C. What is the empirical formula of a substance containing 1.0 mole of aluminum for every 3.0 moles of fluorine?
   D. What is the empirical formula of a substance containing X moles of element A for every Y moles of element B?

12. Cl_2 + 2 NaI yields 2 NaCl + I_2
How many moles of NaCl will form from 3 moles of Cl_2?
A. Cl_2 + 2 NaI yields 2 NaCl + I_2
How many moles of NaCl will 3 grams of NaCl be?
B. X_a + a YZ yields a YX + Z_a
How many moles of YX will form from $\underline{M}$ moles of X_a?
C. F_2 + 2 KBr yields 2 KF + Br_2
How many moles of KF will form from 5 moles of F_2?
D. Cl_2 + 2 NaI yields 2 NaCl + I_2
How many grams of NaCl will form from 3 moles of Cl_2?

13.

Molar Heat of Melting	Specific Heat	Melting Point	Compound
6.8 kcal/mole	0.21 cal/g·deg C	800 degrees C	sodium chloride
1.4 kcal/mole	1.0 cal/g·deg C	zero degrees C	water
M kcal/mole	S cal/g·deg C	T degrees C	X

How much heat must be removed to freeze 15 grams of water at zero degrees C?
A. How much heat must be removed to freeze 6.0 grams of sodium chloride at 800 degrees C?
B. How much heat must be removed to freeze $\underline{G}$ grams of compound $\underline{X}$ at $\underline{T}$ degrees C?
C. How much heat must be removed to freeze 15 grams of water at 15 degrees C?
D. How much heat must be removed to cool 15 grams of water by one degree C?

14. $c = 3.0 \times 10^{10}$ cm/sec $\qquad$ $h = 9.52 \times 10^{-14}$ kcal/sec·mole
What is the frequency of radiation of wavelength 1.2×10^{-6} cm?
A. What is the frequency of radiation of wavelength $\underline{X}$ cm?
B. What is the frequency of radiation of wavelength 5.8×10^{-9} cm?
C. What is the energy of radiation of wavelength 1.2×10^{-6} cm?
D. What is the velocity of radiation of wavelength 1.2×10^{-6} cm?

APPENDIX D

Sample Solutions

Problem Solving Test One

1. Cl_2 + 2 NaI yields 2 NaCl + I_2

How many moles of NaCl will form from 5 moles of NaI?

NaI --- NaCl	1 point
2 NaCl are formed from 2 NaI	2 points
2/2 x 5 are formed	3 points
5 moles NaI form 5 moles NaCl	4 points

2. The charge of one mole of H^+ ions is 9.6×10^4 coulombs. What is the charge of one proton?

one proton = ine H^+	1 point
6×10^{23} H^+ = 1 mole protons	2 points
$\frac{9.6 \times 10^4 \text{ coulombs}}{6.0 \times 10^{23} H^+}$ H^+ is proton	3 points

$$\frac{9.6 \times 10^4}{6.0 \times 10^{23}} = 1.6 \times 10^{4 - 23}$$

$= 1.6 \times 10^{19}$ coulombs, charge of one proton — 4 points

3. How many moles are 6 liters of fluorine at 1.0 atm., 273 K?

1 mole is 22.4 liters	1 point
1.0, 273 STP 6 liters smaller than one mole	2 points
6/22.4 liters	3 points

$$\frac{22.4}{1} = \frac{6}{x}$$

x = 0.2678 moles — 4 points

4. What is the molarity of 1.5 liters of solution containing 4 moles of sodium chloride?

M - molarity	1 point
M = 4/1.5	3 points
4 moles in 1.5 liters make a 2.7 M solution	4 points

5. The mass of an atom of chlorine is 37 a.m.u. How many protons has the atom?

Cl	1 point
chlorine, #17, 35, 45	2 points
17 protons because the atomic number is 17	4 points

6. How many moles are 5 liters of nitrogen at 2.5 atm, 375K?

$\frac{375}{273}$ — 1 point

$\frac{5}{22.4} = 0.22$ moles at STP — 2 points

$5 \times \frac{2.5}{1} = 12.5 = 12.5 \times \frac{273}{375} - 9.1$ moles — 3 points

22.4 liters $\times \frac{1}{2.5} = 8.96$ liters

8.96 liters $\times \frac{375}{273} = 12.3$ liters

$\frac{5}{12.3} = 0.41$ moles — 4 points

7. How many moles are 3 liters of oxygen at 1.0 atm., 225 k?

x = moles — 1 point

$3 \times \frac{225}{273} = 2.5$ moles — 2 points

$\frac{273}{225} = 1.21$

$1.21 \times 3 = 3.63$ liters — 3 points

8. Molar Heat of Melting = 1.4 kcal/mole
Specific Heat = 1.0 cal/g
Melting Temperature = zero degrees C

How much heat must be removed to freeze 15 grams of water at zero degrees C?

zero is freezing — 1 point

$15 \times 1.0 \times 0 = 0$

$15 \times 1.4 = 21$ kcal — 2 points

$\frac{15}{x} = \frac{18}{1.4}$ 3 points

1.17 kcal removed to freeze 15 g. 4 points

9. How many moles of potassium nitrate are required to prepare 1.5 liters of 2.5 molar solution?

$\frac{KNO_3}{1.5}$ 1 point

$\frac{2.5 \text{ moles}}{1.5 \text{ liters}} = 1.7$ moles 2 points

1.5 x 2.5 3 points

x = moles
V = 1.5 liters
M = 2.5 molar

$M = \frac{x}{V}$

$2.5 = \frac{x}{1.5}$

2.5 x 1.5 = x

3.75 = x

3.75 moles 4 points

10. How many moles are 7 liters of hydrogen at 1.5 atm., 273 K?

22.4 liters, STP 1 point

P x V = P x V

1.5 x 7 = 1 x v 2 points

7 (1.5/1)(273/273) = 10.5 liters 3 points

$\frac{7}{22.4} = 0.31$ moles

0.31 (1.5/1) = 0.47 moles 4 points

11. What is the empirical formula of a substance containing 1.0 mole of sulfur for every 2.0 moles of oxygen?

SO 1 point

$2\ S + 2\ O_2$ --- $2\ SO_2$ 3 points

$S_{1.0}O_{2.0}$ 4 points

12. Cl_2 + 2 NaI yields 2 NaCl + I_2
How many moles of NaCl will form from 3 moles of Cl_2?

x moles of NaCl from 3 moles 1 point

$\frac{2}{2} = \frac{3}{x} =$

x = 3 moles 2 points

$3\ Cl^2$ + 2 NaI --- 2 NaCl + I_2 + 2 Cl_2 3 points

(1/3) = (2/6)
6 moles 4 points

13. How many moles of lithium oxide, Li_2O can be formed from 3.6 moles of lithium?

Li_2O 1 point

1/2 the moles of Li 3 points

$\frac{1}{2}(3.6)$ = 1.8 moles of Li_2O 4 points

14. $c = 3.0 \times 10^{10}$ cm/sec $h = 9.52 \times 10^{-14}$ kcal'sec/mole

What is the frequency of radiation of wavelength 1.2×10^{-6} cm?

freq. = x, h = 9.52, w = 1.2, c = 3.0 1 point

$x = \frac{c}{w}$ 2 points

$$1.2 \times 10^{-6} = \frac{3.0 \times 10^{10}}{X}$$

$X = 3.6 \times 10^{4}$ 1/sec 3 points

$$f = \frac{3.0 \times 10^{10} \text{ cm/sec}}{1.2 \times 10^{-6} \text{ cm}}$$

$f = 2.5 \times 10^{16}$ 1/sec 4 points

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