Educational research

# Students' understanding of matter: the effect of reasoning ability and grade level

**Ayhan Yilmaz* and Elvan Alp****

**Hacettepe University, Faculty of Education, Department of Secondary Science and Mathematics Education, Ankara, Turkey*
*e-mail: ayhany@hacettepe.edu.tr*
***Middle East Technical University, Faculty of Education, Department of Elementary Education, Ankara, Turkey*
*e-mail: ealp@metu.edu.tr*

Received 1 June 2005, accepted 5 January 2006

**Abstract:** This study aims at investigating the effect of grade level on students' achievement in matter concept and reasoning abilities, when their test anxiety was controlled. The data was collected from 8th, 10th and 11th grade students by the administration of The Matter Concept Test, Test of Logical Thinking, and the Motivated Strategies for Learning Questionnaire. The results revealed that there was a significant effect of grade level on students' achievement in favor of 11th grade students and the linear combination of reasoning abilities was significantly related to students' achievement. In the Matter Concept Test, the 10th graders did better than 8th graders and the 11th graders did better than either. The only exception to this general observation was the 8th graders' better performance on a small number of questions, which related to topics that were taught and nationally examined in the 8th grade. It seems likely, therefore, that the more chemistry a student is taught the better he/she is likely to be, except that if a topic is examined while it is reasonably fresh in a student's mind the results are likely to be better than if the test is carried out 2-3 years later. [*Chem. Educ. Res. Pract.,* 2006, **7** (1), 22-31]

**Keywords:** chemical education research, cross-age, reasoning ability, matter, test anxiety

## Introduction

The development of the concept of matter is one of the fundamental aims of chemistry courses. In Turkey, the elementary chemistry curriculum as a part of science course begins with a brief introduction of the matter concept at the age of 12-13. It is expected that the aspects of matter concept progress in a sequence from recognizing states of matter, physical and chemical changes, differentiating pure substances from mixtures, decomposition of compounds, combination of elements and atomic structure models during the course. Then, at the age of 13-14 the students are taught chemical bonding and conservation of mass which underlie the matter concept. For high school students at the age of 14-15, the formal chemistry lessons concentrate on the solubility of gases in water, change in terms of atoms and molecules, separation of components of a mixture, and the structure of matter.

Some cross-age studies have been conducted in which the explanations of how children classify different sets of substances were explored. Lovell (1971) suggested that differentiation



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between the properties of objects in a set is the first step in the process of classification. This is followed by the differentiation of properties that are specific to an object from those which are common to the set. Generalization of the characteristics that form the sets leads to the development of new concepts. Literature review has shown that schoolchildren from age 11 to 14 develop undifferentiated alternative concepts on ‘object’ and ‘matter’ (Johnson, 1998; Solomonidou & Stavridou, 2000). Students at these early ages could not discriminate the concepts of object from the concepts matter.

Krnel, Glazar & Watson (2003) explored how the ability to recognize a substance in various objects changed with age. The authors focused on two aspects of the criteria used for the classification. The first aspect was whether the classification was based mainly on intensive properties or on a mixture of intensive and extensive properties. The second aspect was the role of action in developing a scheme that leads to differentiation of matter and object. They proposed that one key feature in the early development of the concept of matter is that children learn how to distinguish matter and objects. The differentiation of such interlinked concepts is seen as a key process in the formation of stable scientific concepts. In this process, the authors see the importance of the ability to distinguish between intensive properties that characterize matter and extensive properties that characterize objects. Intensive properties do not change with size, shape, or quantity of objects, and are identical in each part of the object. Therefore, intensive properties characterize the substance of which the object is made. By contrast, extensive properties are changed when objects are divided or the number of objects is changed. A second key feature argued by the authors in the formation of matter concept is that children learn the differentiation of such interlinked concepts by acting upon and observing the natural world. Krnel, Watson & Glazar (2005) conducted a further study in order to investigate the relationship between the formation of object and matter concepts. Consistent with the findings of their previous research, older students preferred to use intrinsic properties of matter to describe the substances, whereas younger students used a mixture of both extensive criteria and intensive criteria to classify substances. It was also indicated that description of objects and substances by their uses, which is also related to intrinsic properties of matter, increased with age. It was attributed to the fact that the relationship between the properties of substances and objects and their use are more emphasized in school at later grades and in everyday life.

In a research study, Novick & Nussbaum (1981) proposed that students’ understanding of basic aspects of matter concept increases as the amount of relevant information presented increases. However, they found that cognitive difficulties raised by certain aspects are real and not overcome by many older students. So, it was suggested that relative difficulty of various aspects of matter concepts should be taken into consideration while preparing curriculum materials. Besides, Stavy (1990) conducted a study to examine the students’ (ages 9-15) conception of changes in the state of matter from liquid or solid to gas, as well as their understanding of the reversibility of the process. The results showed that students who recognized weight conservation in one of the tasks did not necessarily recognize the same in another task. Students thought that gas has no weight, or that gas is lighter than the same material in its liquid or solid state. Until the age of 12, specific perceptual inputs from the task such as color dramatically affected students’ responses to the conservation of weight task.

Lee, Eichinger, Anderson, Berkheimer and Blakeslee (1993) investigated the understanding of the conceptual frameworks that $6^{th}$ grade students use to explain the nature of matter and molecules. They revealed that students’ initial conceptions differed from scientific concepts in various ways. These differences included molecular conceptions concerning the nature,



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arrangement and motion of molecules as well as macroscopic conceptions concerning the nature of matter and its physical changes.

In addition, the study carried out by BouJaoude & Giuliano (1994) revealed that there was a significant relationship between students' reasoning ability and chemistry achievement. Apart from these, results of Abraham, Williamson & Westbrook (1994) in their cross-age study found that both reasoning ability and experience with concepts (grade level) account for the understanding of chemistry concepts: chemical change, periodicity, phase change, dissolution of a solid in water, and conservation of atoms. It was found that differences in understanding across grade level were significant for the concept of chemical change, dissolution of a solid, conservation of atoms and periodicity. Results also indicated that the use of particulate terms increase across the grade level. In addition, reasoning ability was found to be a significant factor for students' understanding of conservation of atoms and periodicity. According to Abraham et al. (1994), cross-age studies where students of different ages are simultaneously sampled can provide insight into the role that reasoning ability and instructional exposure play in the students' development of scientific concepts. In fact, cross-age studies provide an opportunity to observe the shifts in concept development that occur as students' mature in intellectual development, and they receive additional instruction. Studies indicated that although children's notions of scientific phenomena change over time, certain alternative conceptions persist from preschool through university.

In recent years, there have been some researches focusing on how cognitive and motivational factors interact and jointly influence student learning and achievement. The researchers suggested that students need both cognitive skills and motivation to do well in school (Pintrich & Schunk, 2002). The integration of motivational and cognitive factors was facilitated by social cognitive models of motivation assuming that students can be motivated in multiple ways. Accordingly, in the discussion of motivation as an academic enabler, test anxiety was one of the aspects of student motivational factors that should be considered (Pintrich & Linnenbrink, 2002). A variety of evidence suggested that high levels of test anxiety caused students to perform poorly on a test. Individuals with high test anxiety believe that their test scores accurately represent their ability levels (Cassady & Johnson, 2001). Therefore, the present study investigated the effect of grade level on students' understanding of concept of matter and five reasoning modes when their test anxiety was controlled.

## Research Questions

The following questions guided the study:

1. Is there an effect of grade level on students' achievement in matter concepts and reasoning abilities, when their test anxiety was controlled?

2. Is there a relationship between students' reasoning abilities and their achievement in matter concepts?

## Method

### *Sample*

The subjects of this study consisted of thirty 8$^{th}$ grade students from a randomly selected class of an elementary school, thirty 10$^{th}$ grade and thirty 11$^{th}$ grade students from two randomly selected classes of a high school in Ankara. The mean age of 8$^{th}$ grade students was 14.0 years, that of 10 graders' was 16.2 years, while the mean age of 11$^{th}$ graders' was 17.3 years. Schools



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involved in the study were located in an urban area and students came from families with medium to high socioeconomic status.

***Instruments***

The data collected from students included three kinds: (1) The Matter Concept Test, (2) The Test of Logical Thinking, (3) Motivated Strategies for Learning Questionnaire

*Matter Concept Test (MCT).* The Matter Concept Test was developed by the researchers of the present study. It consisted of 15 multiple choice items related to the solubility of gases in water, heat and temperature, changes of state, solubility and ionization, the effect of temperature on the solubility of gases, diffusion of gases, change of state and expansion, change of state and temperature, solid-liquid equilibrium, effect of pressure on boiling point, boiling point and expansion, conservation of mass, elasticity. The questions were related to real life applications of the topics, and written mainly at comprehension and application levels, according to Bloom's Taxonomy.

Three experts in the field of chemistry education examined an initial version of the test regarding: (a) the adequacy of the chemistry content covered in the test with respect to their developmental appropriateness and relationship to the Turkish curriculum, and (b) appropriateness of the distracters. A pilot study of the Matter Concept Test was conducted in one randomly selected elementary school and one randomly selected high school. A total of eighty-three students were enrolled in the pilot study. The format of 2 questions on the solubility of gases in water and the effect of pressure on boiling point was changed due to their ambiguities. Reliability of the test was found to be 0.70 by calculating internal consistency values using Cronbach's alpha.

*Test of Logical Thinking (TOLT).* The Test of Logical Thinking (TOLT) developed by Tobin & Capie (1981) was used to determine the formal reasoning ability of students. The test consists of ten multiple-choice items designed to measure students' five reasoning abilities; namely, controlling variables, proportional reasoning, probabilistic reasoning, correlational reasoning, and combinatorial reasoning. Students select a response from five possibilities and then they are provided with five justifications from which they choose. The correct answer is the correct choice plus the correct justification. Cronbach's alpha reliability of the test was found to be 0.81.

*Motivated Strategies for Learning Questionnaire (MSLQ).* This is a Likert-type questionnaire developed by Pintrich & DeGroot (1990). MSLQ consists of 22 items and 3 scales, namely self-efficacy, intrinsic value, and test anxiety. Only the test anxiety scale of the questionnaire was used in the current study to measure students' affective or emotional reactions to the tests. Test anxiety is one of the important factors affecting science achievement, so it is assigned as covariate.

***Procedure***

The first author visited one elementary and one high school after receiving the permission for the administration of the tests. The students were informed about the purpose of the study and the procedure for completing the instruments. They were also told that their identity would be kept secret, and the results of the tests would not affect their school grades. Furthermore, the students were required to complete the questionnaire on their own, which took about 50 minutes.



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***Statistical Analysis***

The Statistical Package for the Social Sciences (SPSS, version 11.0) was used to analyze data. Means and standard deviations were determined through descriptive statistics to assess participants' reasoning abilities and their achievement on the matter concept test, which were considered as dependent variables. Grade level was regarded as an independent variable. To determine the effect of grade level on students' achievement and their reasoning abilities when test anxiety was controlled, appropriate mean scores were compared by using multivariate analyses of covariance (MANCOVA). MANCOVA is carried out as a procedure to control the effects of an extraneous variable, called a covariate, by partitioning out the variation attributed to this additional variable (Hinkle, Wiersma & Jurs, 1998). Finally, multiple regression analysis was conducted to detect how well the reasoning abilities predicted students' achievement in matter concepts.

**Results**

Descriptive statistics concerning 8$^{th}$, 10$^{th}$ and 11$^{th}$ grade students' responses to MCT and TOLT is summarized in Table 1. MCT aimed to measure students' achievement (ACHV) on matter concepts while TOLT scores were used to measure students' five reasoning abilities; namely, controlling variables (CONT), proportional reasoning (PROP), probabilistic reasoning (PROB), correlational reasoning (CORR), and combinatorial reasoning (COMB).

**Table 1.** Descriptive statistics for eighth, tenth and eleventh grade students with respect to achievement and reasoning abilities.

| | 8$^{th}$ Grade | | | 10$^{th}$ Grade | | | 11 Grade | | |
|---|---|---|---|---|---|---|---|---|---|
| | Max | M | S.D. | Max | M | S.D. | Max | M | S.D. |
| ACHV | 12 | 7.97 | 1.77 | 14 | 9.23 | 3.75 | 15 | 11.77 | 1.99 |
| CONT | 2 | 0.37 | 0.56 | 2 | 1.70 | 0.60 | 2 | 1.73 | 0.45 |
| PROP | 2 | 1.67 | 0.55 | 2 | 1.70 | 0.65 | 2 | 1.80 | 0.55 |
| PROB | 2 | 1.27 | 0.78 | 2 | 1.30 | 0.70 | 2 | 1.67 | 0.61 |
| CORR | 2 | 1.80 | 0.41 | 2 | 1.67 | 0.66 | 2 | 1.90 | 0.31 |
| COMB | 2 | 1.50 | 0.63 | 2 | 1.73 | 0.64 | 2 | 1.93 | 0.25 |

Multivariate analysis of covariance evaluates whether means on the dependent variables (students' achievement and reasoning ability subscores) are the same across levels of independent variable (grade level), adjusting for differences on the covariate, which is test anxiety. Thus, multivariate analysis of covariance (MANCOVA) was conducted to determine the effect of grade level on students' achievement and reasoning ability subscores, when their test anxiety was controlled. Results showed that there was a statistically significant effect of grade level on the collective dependent variables when the test anxiety was controlled Wilks' $\Lambda$= 0.270 $F$(12, 162)=12.44, $p$<0.001. The multivariate $\eta^2$ =0.33 indicated that 33 % of multivariate variance of dependent variables was associated with the independent variable.

The univariate ANOVA on each dependent variable were conducted as follow-up tests to the MANOVA. The results revealed that there was a significant effect of grade level on students' achievement, controlling variables, and combinatorial reasoning, $F$(2, 86)=16.79, $p$<0.001; $F$(2, 86)=57.68, $p$<0.001; and $F$(2, 86)=3.89, $p$=0.024, respectively.



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Follow-up pair wise comparisons based on simple and repeated contrasts were conducted to evaluate the mean differences between grade levels. Significant differences in the adjusted means between 8$^{th}$ and 11$^{th}$ grade students, and 10$^{th}$ and 11$^{th}$ grade students with respect to achievement were found ($p<0.05$). Moreover, results indicated that there were significant differences in the adjusted means between 8$^{th}$ and 11$^{th}$ grade students, and 8$^{th}$ and 10$^{th}$ grade students with respect to controlling variables ($p<0.05$). Also, there was a significant mean difference between 8$^{th}$ and 11$^{th}$ grade students with respect to combinatorial reasoning ($p<0.05$). Eleventh grade students had the largest adjusted mean while 8$^{th}$ grade students had the smallest adjusted mean on these variables. Adjusted means with respect to dependent variables are presented in Table 2. Therefore, 11$^{th}$ grade students appeared to be the most successful on controlling variables and combinatorial reasoning. In addition, although it was not statistically significant, they had the highest mean subscores on TOLT items measuring other reasoning abilities. Moreover, mean scores indicated that 11$^{th}$ grade students outperformed on MCT.

**Table 2.** Adjusted means with respect to achievement and reasoning abilities.

| | 8$^{th}$ Grade M | 10$^{th}$ Grade M | 11$^{th}$ Grade M |
|---|---|---|---|
| ACHV | 8.37 | 8.96 | 11.63 |
| CONT | 0.40 | 1.68 | 1.72 |
| PROP | 1.64 | 1.72 | 1.81 |
| PROB | 1.27 | 1.30 | 1.66 |
| CORR | 1.81 | 1.66 | 1.90 |
| COMB | 1.54 | 1.71 | 1.92 |

When students' responses to individual items were examined, it was also found that percentage of students who answered items correctly was the highest for 11$^{th}$ grade students for all but 3 items. For example responses to item 6 (see Table 3) showed that percentage of correct responses was 23.3, 66.7, and 80.0 for eighth, tenth, and eleventh grade students respectively. This question was based on a daily life experience concerning a property of water that is independent of sample size. Students were required to infer the reason for the breakage of water pipes in very cold days. To be able to answer this question, students had to be able to use their knowledge on changes in density and volume of freezing water, as well as the relationships among these measures. Eleventh grade students performed best on this item.

Similarly, students' responses to item 11 (see Table 3) revealed that eleventh grade students was the most successful on this item as well and they could better use their knowledge on change of state which is an intensive property of matter. To be able to answer this question students had to know when a matter changes state, mass does not change but the physical properties of matter such as density and volume do.

Item 14 aims to test students' ability to distinguish between intensiveness and extensiveness. Student responses to item 14 reflected an increase in the percentage of correct responses across grade levels. While 53.3 % of eighth grade students answered this item correctly, 93.3 % of eleventh grade students selected the correct answer.

However, for 3 items on solubility and ionization, solid-liquid equilibrium, and electrical conductivity, the situation was reverse: percentage of eighth grade students who answered these items correctly was higher than that of eleventh grade students. For example, 63.3 % of eighth grade students answered the item 4 (see Table 3) correctly while 50.0 % of eleventh grade students gave the correct answer. But, in general, as grade level increased, percentage of correct responses increased.



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**Table 3.** Selected items of MCT.

| Example Items | Percentage of Correct Responses | | |
|---|---|---|---|
| | $8^{th}$ Grade | $10^{th}$ Grade | $11^{th}$ Grade |
| Item 4. Under the same conditions, which one of the followings has the poorest electrical conductivity?<br>A. Mercury (at room temperature)<br>B. liquid sodium chloride<br>C. vinegar<br>D. cologne<br>E. soap water | 63.3 | 58.2 | 50.0 |
| Item 6. In very cold days during winter, when water in the water pipes freezes, the pipes break. Which of the following conclusions can be drawn from this information?<br>I. when water freezes, its mass increases<br>II. density of ice is less than that of water<br>III. when water freezes, the distance between water molecules increases<br>A. I-II B. I-III C. II-III D. only III E. I-II-III | 23.3 | 66.7 | 80.0 |
| Item 11. A closed jar with ice cubes in it has been placed on a scale. What will happen when ice cubes melt?<br>A. needle of scale will deflect to left<br>B. needle of scale will deflect to right<br>C. volume of water will be higher than that of ice<br>D. temperature will be below $O^0C$<br>E. temperature of the jar will increase | 44.2 | 64.3 | 78.4 |
| Item 14: Which one of the followings increases if the mass of a pure substance increases under constant temperature and pressure?<br>I. number of molecules per unit volume<br>II. total number of molecules<br>III. volume<br>A. only I B. only II C. only III D. II-III E. I-II-III | 53.3 | 79.2 | 93.3 |

A Multiple Regression Analysis was conducted to evaluate how well the reasoning abilities predicted students' achievement in matter concepts. The linear combination of reasoning abilities was significantly related to students' achievement $F(5, 84)=2.83$, $p=0.021$. The sample correlation coefficient was 0.38, indicating that approximately 14 % of variance of the achievement scores can be accounted for by the linear combination of reasoning abilities. The results of multiple regression analysis are displayed in Table 4. According to Table 4, there was a statistically significant positive relationship between controlling variables and achievement scores. However, the coefficients were not statistically significant for other reasoning abilities, indicating that these variables do not contribute significantly to the model being considered.



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**Table 4.** The results of multiple regression analysis.

| | Beta | T | *p* |
|---|---|---|---|
| CONT | 0.280 | 2.679 | 0.009 |
| PROP | 0.003 | 0.026 | 0.979 |
| PROB | 0.048 | 0.457 | 0.649 |
| CORR | 0.002 | 0.014 | 0.989 |
| COMB | 0.215 | 1.969 | 0.052 |

## Discussion

The key aspect of matter is the appreciation that it is the general term for the material things around us; it is defined as whatever occupies space and can be perceived by our senses. Liu & Lesniak (2004) proposed that matter is a fundamental domain concept in chemistry, since chemistry is a science of matter and its transformations. The progression of students' conceptions of matter determines their mastery of principles and theories of physical and chemical changes. In other words, the students are expected to acquire a satisfactory understanding of physical and chemical changes, changes of state, as well as solubility and ionization to comprehend the processes of matter and the particulate model.

The results of the present study revealed that there was a significant effect of grade level on students' achievement. 11$^{th}$ grade students had the highest mean score on the test indicating higher achievement, while 8$^{th}$ grade students had the lowest score. At this point it should be noted that students' cognitive level may have influence on students' achievement in matter concept. The development of a concept is subject to maturation levels. There is a developmental process in the formation of a concept, parallel to cognitive development. When a word has been learned by the child, its development is barely starting; the word at first is a generalization of the most primitive type; as the child's intellect develops, it is replaced by generalizations of a higher type which lead to the formation of true concepts (Vygotsky, 1986).

Intellectual development influences children's understanding of scientific concepts. Krnel, Glazar & Watson (2003) proposed that as the cognitive level of students increases, their success on the concept test increases. The researchers pointed out that as students grow older and have more experience of the world, they shift from using mixed criteria (extensive and intensive) for classifying objects and substances, to using mainly intensive criteria. As they gain more experience, their focus shifts from the extensive properties of objects which may change from object to object. Therefore, they become aware of intrinsic properties of matter such as color, and state of matter, that are independent of the form in which matter is presented.

The results of the present study are consistent with the findings of the study by Krnel et al. (2003). The Matter Concept Test administered in the present study consisted of examples from daily life as well as some items measuring students' achievement on matter concept emphasized in science courses. It was found that higher grade level students had a better construction of matter concept by means of their experience on the world. Furthermore, student responses indicated that as the grade level increases, their ability to distinguish between intensive properties that characterize matter and extensive properties that characterize objects. This differentiation is seen as a key process to construct stable and scientific concepts.



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Another study by Stavy (1990) showed that very young children understand what the weight of an object is and know that a large body of a certain material is heavier than a smaller body of the same material. However, when children were asked about density which is an intensive property of matter, they responded as if they had been asked about weight, which is an extensive property of matter. These terms are not sufficiently well defined in the child's mind and as long as they are not consciously differentiated the child can be affected by them according to the situation. Consistent with the research results of Stavy (1990), the explanation of state of matter according to the arrangement of these particles has not appeared in early grade level students. The children adapt the particle theory to their own conception according to which solids weigh more than gases. The particulate theory is not internalized, and most of the students do not acquire a satisfactory understanding of this theory although this topic is emphasized at school.

Besides, the Matter Concept Test used in the current study required students to construct a coherent body of scientific knowledge instead of just memorizing facts and definitions. Therefore, it was expected that students who learned matter concepts meaningfully, identifying real life applications of what they know, and relationships among the concepts such as density, volume, and mass, get higher scores on the test. However, apart from students' cognitive level, the amount of relevant information presented, the way of its presentation, and students' prior knowledge may have influence on their understanding. For instance, Novick & Nussbaum (1981) proposed that as the amount of relevant information presented to students increases, their understanding of basic aspects of matter concepts increases. Older students spent more hours in chemistry course per week in school.

It should be also taken into consideration that $11^{th}$ grade students in Turkey prepare for the university entrance examination consisting of questions, most of which deal with the matter concept. Furthermore, the results showed that $8^{th}$ grade students have a better understanding on solubility and ionization, solid-liquid equilibrium and electrical conductivity. Eighth grade students also take a national examination focusing mainly on solubility and ionization, solid-liquid equilibrium, electrical conductivity. These topics are extensively practised during the instruction in that grade to meet the requirements of the examinations.

In this study the role of reasoning ability in student achievement was considered as well as cognition. Recent researches have provided evidence that formal reasoning ability is a significant predictor of academic success in chemistry concepts (BouJaoude & Giuliano, 1994). Consistent with this research finding, the linear combination of reasoning abilities was significantly related to students' achievement. Both reasoning ability and experience with concepts account for the understanding of chemistry concepts. Eleventh grade students appeared to be the most successful in controlling variables and combinatorial reasoning. In addition, although it was not statistically significant, they had the highest mean scores on TOLT items measuring other reasoning abilities. The limited quality of reasoning ability found in younger students could influence their achievement in MCT.

To develop the formation of the matter concept for early grade students, appropriate curriculum materials and instructional strategies should be utilized (Abraham et al., 1994). In this study, achievement scores in MCT were positively correlated with controlling variables. However, the results indicated that other reasoning abilities were not significant determinants of academic success. Other cognitive factors such as prior knowledge may play a more important role than proportional, probabilistic, correlational, and combinatorial reasoning in explaining the observed difference in student performance. Also, factors such as home and school environment, peer and teacher influences, socio-economic variations, family demands, and other student



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characteristics such as attitudes, interests, and motivational beliefs may account more in explaining the variations among student performance for the population of interest.

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