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Algorithmic, Conceptual and Graphical Chemistry Problems: A Revisited Study

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The aim of this study is to determine whether there were significant differences students' performances amongst conceptual, algorithmic and graphical questions tests in selected topics. One hundred 12th grade students participated in this study. In order to address research questions. The conceptual, graphical and algorithmic questions tests were used in topics of solubility, chemical calculations, chemical equilibrium and radioactivity. Students' performances in each test were analyzed with one-way ANOVA and statistical analysis pointed to statistically significant differences amongst each of three test scores ($p < 0.05$) in favour of algorithmic questions test. Further analyses were utilized to compare one type of questions test with others. From these comparisons, it was found the independence of the conceptual dimension, the algorithmic dimension and the graphical dimension. It was concluded that the compe-tence in each type of questions may be independent of other types of questions.

Key Words: Problem solving, Students' performance, Conceptual question, Algorithmic question, Graphical question.

INTRODUCTION

Problem solving is a research topic in chemistry education, in which domain extensive research has been conducted over the past few decades. Many study deal with the modeling of problem solving[1], the types of problems[2], the possibilities for developing problem-solving skills[3], the cognitive variables of the successful problem solving[4], *etc*. Among science educators, there is also a consensus that problem solving has always constituted an essential part of the science curricula and has been considered as a substantial assessment tool[5-10]. Furthermore, helping students acquire problem solving skills has been the basis of science teaching[11]. However it is noted that students-especially novice ones- confronted many difficulties in problem solving[12,13]. Moreover, teachers in different regions of the world have often complained about their students, that the students lack the ability or motivation to go beyond factual material to a sound understanding of course material[14]. Hence, a variety of information has to be processed and understood by students to be succeeding acade-mically[13]. Mentioned information can be presented to students in two distinct modes: algorithmic-mode and conceptual-mode. The breakdown of chemical understanding into algorithmic and conceptual understanding is done primarily through the framework of problem-solving. The two terms explained as follows: algorithmic understanding is defined as the ability to match up or recall an appropriate mathematical formula and a strategy to compute a numerical answer, in other words, the ability to "work problems"[15-17]. Conceptual understanding is defined as the ability to determine what ideas are relevant and important to a problem and which are not, as well as accurately understand the connections between microscopic behaviour, macroscopic observations and the chemical symbols and notations used to represent both[15-18].

In the literature, there have been different ways in order to determine whether students are algorithmic or conceptual problem solvers in chemistry[19,20]. These are: problem solving networks[21,22], tests which involve M-demand of different items of content[23-26] and most commonly usage is asking students pairs of algorithmic and conceptual questions[13,15-17,27-34]. In the last mentioned approach, researchers asked students two questions related to the same topic (named as paired questions). One question involves conceptual understanding while the other involves algorithmic skills. Preliminary written articles[16,17,33] using the mentioned approach found that most of the students use algorithms to solve chemistry problems and that many of them have inadequate understanding of the concepts involved. In the light of just mentioned finding, a series of studies and articles[15,27,28,32,34,35] have attempted to determine or to verify whether the widespread assumption is reasonable or not. Findings by various researchers[13,32,33,35,36] confirmed the widespread assumption that the ability to apply algorithm to solve large numbers of problems does not signify conceptual understanding. Furthermore, Niaz and Robinson[37] stated that student training in algorithmic-mode problems did not guarantee sound understanding of conceptual problems since the two problems may require different cognitive abilities. On the other hand a few studies, reported by Chiu[27], Costu[20] and Yilmaz *et al.*[34], found that students were able to solve algorithmic problems and show satisfactory conceptual understanding of chemistry, *i.e.*, they showed high performance in both questions (conceptual and algorithmic). The finding affirmed by Niaz[38] and Papaphotis and Tsaparlis[39] with the statement that students showing conceptual understanding are probably to be also successful in solving computational problems than the other way round. In parallel with the studies, Lin *et al.*[28] found that there were no significant differences between students' performance on the conceptual and algorithmic questions. In addition to mentioned studies, a few studies[39-42] extended conceptual and algorithmic questions such as "simple algorithmic", "demanding algorithmic", "conceptual understanding and critical thinking", "well-practiced (algorithmic) questions" *etc.* In summary, general tendency with a few contradictions is that students tend to learn and solve problems "algorithmically" but often do not grasp the deeper conceptual aspect of chemistry and reasoning necessary to be more creative problem solvers.

Costu[20] first combined conceptual and algorithmic understanding (discussed in aforementioned paragraph) with graphical understanding in taking in to account the following assumption that graphical understanding is an important way for students to understand chemistry and its applications[43-45]. The study used three tests (or questions pairs) in order to compare students' performance on conceptual, algorithmic and graphical questions tests. It is found that statistically significant differences amongst the three test scores in favour of the conceptual test[20]. Further more, it is also noted[20] that positive relationship between conceptual understanding and algorithmic understanding and between conceptual understanding and graphical understanding. The study also indicated that students show the best performance on conceptual test and the worst performance on graphical test. In the current study, previous paper[20] was extended using four chemistry topics, namely, solubility, chemical calculations, chemical equilibrium and radioactivity in addition to gases state. The four topics investigated also were chosen because of their frequency of occurrence in research literature and in chemistry courses.

The aim of this study is to determine whether there are significant differences students' performances amongst conceptual, algorithmic and graphical questions tests in the selected topics. Three research questions investigated are as follows: (a) Are there significant differences in students' performance amongst conceptual, algorithmic and graphical questions prepared in the selected topics? (b) Do students show the best, the moderate and the worst performance on which of the question type about selected topics? (c) Are there positive relationship amongst conceptual understanding, algorithmic understanding and graphical understanding?

EXPERIMENTAL

Participants in this study comprised of one hundred 12th grade students (47 boys and 53 girls, whose ages ranged from 17-20 years; mean = 18.60), who come from different secondary schools of a city in Turkey. The sample had studied topics of "solubility" "chemical calculations" "chemical equilibrium" and "radioactivity" in their secondary schools.

Data collection instrument and analysis: In order to address research questions asked in this study, conceptual, graphical and algorithmic question tests were utilized. Each test paper contains five questions that were developed by using various chemistry textbooks and question banks. All of the test items were multiple-choice and specification of test items is given in Table-1.

TABLE-1
SPECIFICATION OF THE QUESTION PEERS

Question peers	The topic of the question peers
1A, 1C and 1G	Solubility
2A, 2C and 2G	Solubility
3A, 3C and 3G	Chemical calculations
4A, 4C and 4G	Chemical equilibrium
5A, 5C and 5G	Radioactivity

A: Algorithmic question, C: conceptual question, G: graphical question.

Three examples of each type of test item, based on the same content for chemical equilibrium topic, are presented in Fig. 1.

Sample of algorithmic problem solving question

Question 4A:

At constant temperature, 4,00 mol of CO (g), and 2,00 mol of Cl_2 (g) was introduced into a one-liter container. After reaching CO (g) + Cl_2 (g) ⇌ $COCl_2$ (g) equilibrium, 8,00 mol $COCl_2$ (g) was found in the container.

When $COCl_2$ (g) is added into container, equilibrium is established again and there is 8,00 mol of CO (g) in the container. Calculate what mole of $COCl_2$ (g) has added into container?

A) 40 mol **B)** 36 mol **C)** 52 mol **D)** 50 mol ***E)** 44 mol

Sample of conceptual understanding question

Question 4C:

For the equilibrium

PCl_3 (g) + Cl_2 (g) ⇌ PCl_5 (g)

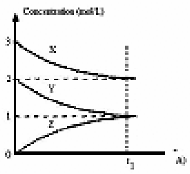
When a little PCl_5 (g) is added into container at constant temperature and volume, which of the change or changes given below would be occurred?

I. Decrease the concentration of PCl_3 (g)
II. Increase the concentration of Cl_2 (g)
III. Increase total mol of the gases

A) Only I **B)** Only II **C)** I and II ***D)** II and III **E)** I, II and III

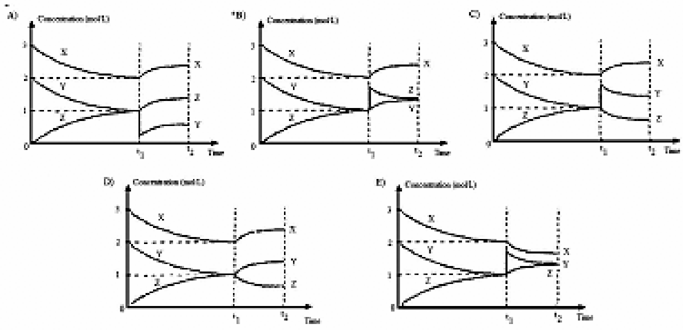
Sample of graphical understanding question

Question 4G:



Graph (concentration-time) of an equilibrium in constant volume container is given in the left side.

If a little Z (g) is added into the container, how would the graph change. Which of the graph given below correctly illustrates the changes?



* **Note:** The correct answer for each question is indicated by an asterisk

Fig. 1. Examples of three types of questions (algorithmic problem solving question, conceptual understanding question and graphical understanding question) about chemical equilibrium (question 4)

As seen in Fig. 1, Question 4A required the student to work through an algorithm to find a numerical solution to a chemical equilibrium problem, considered as algorithmic question. Question 4C required students to use their conceptual knowledge about the topic to select a reasonable answer, considered as conceptual question. Question 4G required students to use graphical knowledge and interpretation, considered as graphical question. In addition, besides algorithmic, conceptual and graphical questions, a fourth question was added to ask students about their preference for algorithmic, conceptual or graphical questions.

All test items were pilot tested on 30 students and reliability of the tests was calculated. The entire test items were multiple-choices and each of the correct answers were scored 1 point. The Cronbach's alpha reliability coefficient of the three tests was found to be very close to each other (0.67 for conceptual questions test, 0.65 for algorithmic questions test and 0.63 for graphical questions test). The tests were validated by a panel consisting of three chemistry teachers and two researchers. Furthermore, it was computed indexes of discrimination for each test items and found as equal to and higher than 0.25 for all items.

One hundred 12th grade students took the examination in one 25 min session. All of the students answered the whole set of test questions (15 test items). As for data analysis, a scoring scheme was developed to measure students' performance. The scoring scheme was designed to have 0 (incorrect) or 1 (correct) point. Answers coding no response to questions were scored 0 point in analyzing categories and their frequencies were given for students' preference.

RESULTS AND DISCUSSION

The students' responses in each set of questions are presented in Table-2. As can be seen from the Table-2, most students gave correct responses to algorithmic type of questions and had more difficulty with graphical questions for all items (or for four topics). Most students gave incorrect answers to graphical questions in all sets of questions. Furthermore, more students gave no response to graphical questions in comparison with the other types.

TABLE-2
STUDENTS' RESPONSES IN EACH TYPE OF QUESTIONS (ALGORITHMIC, CONCEPTUAL AND GRAPHICAL QUESTIONS)

Question papers	A1	A0	A-	C1	C0	C-	G1	G0	G-
1A, 1C and 1G	89	11	0	77	16	7	60	34	6
2A, 2C and 2G	83	12	5	69	22	9	56	34	10
3A, 3C and 3G	86	10	4	80	16	4	68	25	7
4A, 4C and 4G	87	8	5	73	23	4	50	38	12
5A, 5C and 5G	92	8	0	75	17	8	60	38	2
Total	437	49	14	374	94	32	294	169	37

A1: Algorithmic question correct, C1: conceptual question correct, G1: graphical question correct. A0: algorithmic question wrong, C0: conceptual question wrong, G0: graphical question wrong. A-: no response to algorithmic question, C-: no response to conceptual question, G-: no response to graphical question.

Differences in each category, algorithmic, conceptual and graphical questions were examined for statistical significance by means of SPSS (One-Way ANOVA) and given in Table-3.

TABLE-3
RESULTS OF ANOVA

	Sum of squares	df	Mean square	F	Sig.
Between groups	41602.667	2	20801.333	37.039	0.000*
In groups	166796.000	297	561.603	–	–
Total	208398.667	299	–	–	–

*The mean difference is significant at the 0.05 level.

As can be from the Table-3, there were statistically significant differences amongst the test scores ($p < 0.05$) in favour of algorithmic questions test. That is, students had significantly the best performance on algorithmic questions among all types of questions. Students had the worst performance on graphical questions and moderate performance on conceptual questions. Moreover, the data was analyzed by means of SPSS 10.0™ to make multiple comparisons based on the Tukey test. The results were shown in Table-4.

TABLE-4
MULTIPLE COMPARISONS OF THE TESTS SCORES ON BASIS OF THE TUKEY TEST

Tukey test		Mean difference (I-J)	Std. error	Sig.
(I) Test	(J) Test			
Conceptual questions	Graphical questions	15.800*	3.351	0.000
	Algorithmic questions	-13.000*	3.351	0.000
Graphical questions	Conceptual questions	-15.800*	3.351	0.000
	Algorithmic questions	-28.800*	3.351	0.000
Algorithmic questions	Conceptual questions	13.000*	3.351	0.000
	Graphical questions	-28.800*	3.351	0.000

*The mean difference is significant at the 0.05 level.

It can be seen that multiple comparisons suggest that there was a statistically significant difference between conceptual questions test and algorithmic questions test ($p < 0.05$) and between conceptual questions test and graphical questions test ($p < 0.05$) and between algorithmic questions test and graphical questions test ($p < 0.05$). Students' preferences for each type of questions are listed in Table-5.

TABLE-5
STUDENTS' SELF PREFERENCE ON EACH TYPE OF QUESTION

Algorithmic preference		Conceptual preference		Graphical preference	
f	%	f	%	f	%
53	53	30	30	17	17

As seen from the Table-5, it should be noted that while more students (53 %) prefer algorithmic questions, moderate percentages of the students (30 %) prefer conceptual questions and few students (17 %) prefer graphical questions, which are consistent with statistical findings. Students who claimed to prefer algorithmic problem did the best in algorithmic type of questions among all types of questions (30 %). Students who claimed to prefer conceptual question did the best in conceptual types of questions (27 %). Similarly, students who self-declared a graphical preference had the highest correct rate in the graphical types of questions (23 %). Conversely, a few students had highest performance on questions different from their declared preference (20 %).

The coding scheme used by earlier studies[13,15,27] was modified. In order to make comparison between algorithmic problems (coded A) and conceptual understanding questions (coded C) or between algorithmic problems (coded A) and graphical questions (coded G) or between conceptual understanding questions (coded C) and graphical questions (coded G), respectively; students were assigned to one of the two groups in each category. Whenever a student's total score was over 50 % (3 out of 5 points, one point for each test item), he was categorized as a high performer (H) in the category. If a student scored less than 50 %, he was categorized as a low performer (L). The codes for each item are based on the combination of the student's performance on each question in the pairs. All the possibilities about comparisons are shown in Fig. 2.

The criterion was also used to assess the students' performance on the algorithmic problems *versus* the conceptual questions or algorithmic problems *versus* graphical questions or conceptual questions *versus* graphical questions, respectively. With respect to comparison between students' performance on the algorithmic problems and the conceptual questions, a similar coding scheme was also applied to responses on each test item. A correct answer on a conceptual question is coded as **HC**; an incorrect answer on an algorithmic problem is coded as **LA**. All the possibilities are shown below.

HAHC: Algorithmic problem high achievement; conceptual question high achievement. **LAHC:** Algorithmic problem low achievement; conceptual question high achievement. **HALC:** Algorithmic problem high achievement; conceptual question low achievement. **LALC:** both questions low.

The distributions of student total performance were: **HAHC**, 58 %; **LAHC**, 8 %; **HALC**, 32 % and **LALC**, 2 % as seen in Fig. 2. A description of the students in each category and distributions are shown in the Fig. 2. This figure indicated that most of the students were able to apply correct concepts to solve the problems on the selected topics. The figure also indicated that more students (32 %) solve algorithmic problems without proper conceptual understanding. In order to examine in detail, the analyses of students' performance on each item were presented in Table-6.

As seen from the Table-6, the students showing **HAHC** performance were the highest percentage in all performance categories. The students had a slightly highest percentage for **HALC** scores that means it was likely for a student to have a high performance on algorithmic question and incorrectly answer the conceptual question. These findings indicated that the students solve algorithmic problems without proper conceptual understanding about selected topics, which were consisted with in the other researchers'[12-17,33] as well as the Fig. 2.

		Conceptual question (C): High (H)	Conceptual question (C): Low (L)
Algorithmic problem (A)	High (H)	Good at algorithmic problems, good at conceptual questions **(HAHC)** 58 %	Good at algorithmic problems, poor at conceptual questions **(HALC)** 32 %
	Low (L)	Poor at algorithmic problems, good at conceptual questions (LAHC) 8 %	Poor at algorithmic problems, poor at conceptual questions (LALC) 2 %

		Algorithmic problem (A): High (H)	Algorithmic problem (A): Low (L)
Graphical question (G)	High (H)	Good at algorithmic problems, good at graphical questions **(HAHG)** 41 %	Good at graphical problems, poor at algorithmic problems **(HALG)** 3 %
	Low (L)	Poor at graphical questions, good at algorithic problems **(HALG)** 49 %	Poor at algorithmic problems, poor at graphical questions **(LALG)** 7 %

		Graphical question (G): High (H)	Graphical question (G): Low (L)
Conceptual question (G)	High (H)	Good at graphical questions, good at conceptual questions **(HCHG)** 29 %	Good at conceptual questions, poor at graphical questions **(HCLG)** 35 %
	Low (L)	Poor at conceptual questions, good at graphical qudstions **(LCHG)** 15 %	Poor at conceptual questions, poor at graphical questions **(LCLG)** 21 %

Fig. 2. Categories of students (algorithmic questions versus conceptual question, algorithmic questions versus graphical question and graphical questions versus conceptual question)

With respect to comparison between students' performance on algorithmic problems and graphical questions, the same coding scheme was also applied to responses on each test item. A correct answer on an algorithmic problem is coded as **HA**; an incorrect answer on a graphical question is coded as **LG**. All the possibilities are shown below.

HAHG: Algorithmic problem high achievement; graphical question high achievement. **LAHG:** Algorithmic problem low achievement; graphical question high achievement. **HALG:** Algorithmic problem high achievement; graphical question low achievement. **LALG:** both questions low.

TABLE-6
PERCENTAGE CORRECTION IN EACH TEST ITEMS ON ALGORITHMIC AND CONCEPTUAL QUESTIONS

Questions	HA		LA	
	HC	**LC**	**HC**	**LC**
1	65	24	10	1
2	53	30	16	1
3	70	15	10	5
4	64	22	9	5
5	70	22	5	3
Average	64	22	10	3

The distributions of student total performance were: **HAHG**, 41 %; **LAHG**, 3 %; **HALG**, 49 % and **LALG**, 7 %. A description of the students in each category and distributions are shown in Fig. 2. Generally, this figure indicated that most of the students were able to apply algorithmic thinking to understand and to not interpret graphical representation on the selected topics. It can also be concluded that percentages of the performance categories for **LG** are highest (56 %), which indicates lowest performance on graphical understanding questions. For detailed examination, the analyses of students' performance on each item were presented in Table-7.

TABLE-7
PERCENTAGE CORRECTION IN EACH TEST ITEMS ON ALGORITHMIC AND GRAPHICAL QUESTIONS

Questions	HA		LA	
	HG	**LG**	**HG**	**LG**
1	55	34	6	5
2	45	38	11	6
3	59	27	9	5
4	44	43	6	7
5	56	36	4	4
Average	52	36	7	5

As seen from the Table-7, the students showing **HAHG** performance were the highest percentage for all questions. At first glance, it was recognized that there is connections between students' algorithmic problem solving skills and graphical understanding. That is, most of the students were able to solve the problems on the selected topics and to read and interpret graphs correctly on the selected topics. However they had a slightly highest percentage for **HALG** scores that means it was likely for a student to have a high performance on algorithmic question and incorrectly answer the graphical question.

With regard to comparison between students' performance on conceptual questions and graphical questions, the same coding scheme was also applied to responses on each test item. A correct answer on a conceptual question is coded as **HC**; an incorrect answer on a graphical question is coded as LG. All the possibilities are shown below.

HCHG: Conceptual question high achievement; graphical question high achievement. **LCHG**: Conceptual question low achievement; graphical question high achievement. **HALG**: Conceptual question high achievement; graphical question low achievement. **LALG**: both questions low

The distributions of student total performance were: **HCHG**, 29 %; **LCHG**, 15 %; **HCLG**, 35 % and **LCLG**, 21 %. A description of the students in each category and distributions are shown in Fig. 2. This figure indicated that most of the students had powerful conceptual understanding; however, had poor graphical understanding. It can also be concluded that percentages of the performance categories for **LG** are highest (56 %) which indicates lowest performance on graphical understanding questions. In order to examine in detail, the analyses of students' performance on each item were presented in Table-8.

TABLE-8
PERCENTAGE CORRECTION IN EACH TEST ITEMS ON CONCEPTUAL AND GRAPHICAL QUESTIONS

Questions	HC		LC	
	HG	LG	HG	LG
1	45	30	15	10
2	43	27	14	16
3	52	28	16	4
4	38	36	12	14
5	48	27	12	13
Average	45	30	14	11

As seen from the Table-8, students showing **HCHG** performance had the highest percentage. At first glance, it was recognized that there is connections between students' conceptual understanding and graphical understanding. That is, students who have good conceptual understanding also have good graphical understanding. However they had a slightly highest percentage for **HCLG** scores that means it was likely for a student to have a high performance on conceptual question and incorrectly answer the graphical question.

Conclusion

The overall study has demonstrated the differences amongst conceptual understanding, algorithmic understanding and graphical understanding in the case of the selected topics. Let us consider now the answers to two relevant research questions. **Are there significant differences in students' performance amongst conceptual, algorithmic and graphical questions prepared in the selected topics? Do students**

show the best, the medium and the worst performance on which of the question type about selected topics?

Results obtained show that there were statistically significant differences amongst the test scores in favour of algorithmic questions test in the selected topics. The students had significantly the best performance on algorithmic questions among all types of questions. From multiple comparison, it was also found that there was a statistically significant difference between conceptual questions test and algorithmic questions test ($p < 0.05$) and between conceptual questions test and graphical questions test ($p < 0.05$) and between algorithmic questions test and graphical questions test ($p < 0.05$).

As aforementioned above, students had significantly the best performance on algorithmic questions among all types of questions, which was in contradiction with previous study[20] about topic of gases. In a similar manner, most of the students preferred algorithmic questions among them. Both quantitative and self-preference questionnaire findings indicated that the students tended to do the best on algorithmic questions. The finding was consistent with the general tendency reported in the literature[12,13,15-17,30,31,33] that a fairly large number of chemistry students are algorithm problem solvers. There may be some major reasons for this result. However one of them discussed in here. The reason is attributed to traditional learning environment and teaching, as explained by Okanlawon[32] as follows:

"*...in a traditional chemistry class, the predominant method of delivering instruction is lecture. This instruction gives attention to the sequence of steps used to solve the problem rather than the underlying principles upon which the problems is based. Students were then assigned practice problems analogous to the worked-out examples with the assumption that such practice will result in an improved performance. Mostly, they work on the problems individually and alter submitting their work for assessment....*" (pp. 146-147).

Taking into account that reason, it is suggested that chemistry teachers should change their tradition teaching methods, which may encourage students problem solving with mathematical ability without understanding the underlying chemistry concept, towards more student-centered teaching, which may encourage problem solving with proper conceptual understanding.

On the other hand, the result was inconsisted with other studies[20,27,28,34] which were found that there were no significant differences between students' performance on conceptual and algorithmic questions or that students were able to solve algorithmic problems and show a correct conceptual understanding of chemistry.

Results obtained also indicated that the students had the worst performance on graphical questions and medium performance on conceptual questions in the selected topics. Similarly, average percentages of the students (30 %) preferred conceptual questions and a few students (17 %) preferred graphical questions. Both overall statistical analysis and comparisons among students' score in each test showed that students' performances on graphical questions were the lowest among all types of questions. This finding was affirmed by previous study[20]. The result of the present study is in harmony with many research findings indicating that students have many difficulties about graphical tasks[43-47] and that students cannot effectively use the graphical skills[48,49]. In a recently published paper[49], it was investigated whether such mathematically related problems are due to deficiencies in their mathematics foundation or due to the complexity introduced by transfer of mathematics to a new scientific domain. The paper concluded that the problem seems to lie at the mathematics side and is not due to the transfer of mathematics to an application. Their finding was partly confirmed in the present study in which there was found that the students show poor graphical understanding despite fairly good conceptual understanding. The paper was also found that students' graphical construction and interpretation skills are inadequate and that students show the poor performance in both the mathematics and the chemistry results of the graphical question. Their prevision and findings about graphs was corroborated by the present study about three chemistry topics and previous study[20] about gases, in which compared students' performance on algorithmic, conceptual and graphical problems. Taking into account that lack of graphical skills makes graphical questions difficult for most students, in this regard, it should be placed emphasis on providing students graphical skills when teaching mathematics and chemistry. Potgieter *et al.*[49], put forward to similar suggestions with following statements:

"*... more emphasis should be put on cultivating graphical skills when teaching mathematics; this includes construction as well as interpretation of graphs. This should be done, not only for the sake of deeper conceptual understanding within mathematics itself, but especially for understanding within applied fields such as chemistry... ...a graphical approach to processes in chemistry should be encouraged and expanded upon. It is regrettable that few textbooks illustrate the process under discussion using a graphical representation to enhance conceptual understanding...* ." (p. 214).

Furthermore it should be utilized computer aided instruction in order to improve students' graphical skills. One was accomplished with the case-based computerized laboratory, named as CCL[43] by which students' graphical skills significantly improved.

Are there positive relationship amongst conceptual understanding, algorithmic understanding and graphical understanding?: From comparison one type of questions with others, it was found the independence of the conceptual dimension, the algorithmic dimension and the graphical dimension, which was in contradiction with previous studies[20, 27]. The interpretation of the statistical analysis is not that the three abilities cannot be exhibited by the same person, but that the level of performance in one dimension does not depend on the level of performance in the other dimensions. That is, it was concluded that competence in each type of questions may be independent of other types of questions, that is 'algorithmic understanding' does not presuppose "conceptual understanding" and 'conceptual understanding' does not presuppose "graphical understanding".

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