ALGORITHMIC APPROACH TO QUANTITATIVE PROBLEM-SOLVING IN CHEMISTRY

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Abstract

Examining students' inclinations to use algorithms and rules to solve a task was a fruitful area of research in chemical education in the last four decades. This research aimed to examine whether students read the task request carefully, considering its meaningfulness, or they approach it mechanically, applying a set of algorithms by default. The research sample consisted of students majoring in chemistry teaching at the University of Novi Sad, Faculty of Sciences who were in their final year of bachelor studies. The study was conducted during two academic years. The main instrument consisted of five quantitative problems, and each of the problems contained deceptive information that made the calculation nonsensical. The results revealed that most students applied an algorithmic approach without paying attention to the meaningfulness of the task requirements. Additionally, it has been shown that students rely heavily on memorizing formulas without a proper understanding of underlying concepts.
Keywords: *algorithms, conceptual understanding, quantitative problems*

Introduction

One of the most important outcomes of chemical education is the development of conceptual understanding (Rodić, 2018). There are many definitions of conceptual understanding suggested so far which are mostly intuitive. This study relies on a definition proposed by Holme et al. (2015) which resulted from extensive research and meets the most comprehensive requirements of the chemistry education community. It describes the conceptual understanding across five dimensions: (i) *transfer* (student's ability to apply main ideas in chemistry to novel chemical situations), (ii) *depth* (reasoning beyond memorization and algorithms), (iii) *prediction* (ability to explain behaviour of chemical systems), (iv) *problem solving* (reasoning involved in solving problems) and (v) *translation* (ability to translate between scales and representations). However, although conceptual understanding is a desirable learning outcome, in practice, students are far more in favour of the algorithmic approach. There is strong evidence that students are inclined to use algorithmic problem-solving strategies without engaging in conceptual reasoning (Cracolice et al., 2008; Lazenby & Becker, 2019).

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This may be related to the fact that school chemistry around the world is organized in such a way that it is subordinated to the success of students in the final examinations (Stamovlasis et al., 2005). Therefore, teachers are often forced to dedicate the vast majority of their teaching time to practising very complex calculations. In that way, students become experts in calculations, and at the same time, they do not understand the conceptual basis of the content itself.

This research aimed to examine whether students – future chemistry teachers from Novi Sad, have a mechanical/algorithmic or conceptual approach to solving quantitative problems in chemistry. The main idea was to find out whether students read the request carefully, considering its meaningfulness, or they approach it mechanically, applying a set of algorithms by default. Accordingly, the following research questions were set up:
RQ 1: Do students possess declarative knowledge regarding some selected concepts?
RQ 2: Do they activate that knowledge during the problem-solving process, or such knowledge is dysfunctional?

Research Methodology

Study Sample

Two generations of future chemistry teachers took part in this research. Both groups were in their fourth (final) year of bachelor studies. There were 22 students, 12 in the academic 2016-2017 and 10 in the academic 2017-2018. Of the total sample, 3 students were male and 19 were female. Although the total sample was 22 students, it is representative since it encompasses all students of the target group (students majoring in chemistry teaching at the University of Novi Sad) over two academic years. In addition, this study has mainly a qualitative character and the sample cannot have much impact on research outcomes.

All respondents agreed to volunteer in the research. They were explained that their answers and results are going to be used for research purposes without any compensation and that they can opt-out of the study at any point.

Research Instrument

Two instruments were used in the research. The first instrument (T1) was a paper and pencil test with four multiple-choice tasks, which were designed to provide the answer to RQ1. This test examined declarative knowledge such as the knowledge of insoluble compounds and metals in water, the relative position of metals in activity series, and molar volume. T1 questions are given in Box 1.

Box 1. T1 questions
Q1. Which answer includes all the following that are insoluble in water? Circle the letter of the correct answer.
a) $AgCl$, $NaNO_3$, $Ba(NO_3)_2$ b) $AgCl$, $BaSO_4$, $Al(OH)_3$
c) $Ba(NO_3)_2$, $AgCl$, KCl d) KCl, $AgCl$, $Al(OH)_3$
Q2. Circle the letter of the correct answer. Which of the following metals does not dissolve either in hot or cold water, under standard pressure?

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a) Al b) K c) Mg d) Ca

Q3. Circle the letter of the correct answer. Which of the gases bellow is product of the reaction between copper and concentrated sulfuric acid?

a) H_2 b) H_2S c) SO_2 d) H_2O

Q4. Circle the letter of the correct statement.

The second instrument (T2) was a test consisting of five conceptual tasks (CT). It was designed to provide an answer to RQ2. Each task contained a piece of deceptive information which made the calculation senseless. Namely, students were requested to calculate the molar concentration of the solution, but the compound given was insoluble in water; to calculate the volume of a product, but the reaction was impossible; to calculate the molar volume of a solid substance; to calculate pH value of the solution formed by dissolving the metal in water, but the given metal was insoluble in water. T2 tasks are shown in Box 2.

Box 2. T2 questions

CT1. Calculate the molar concentration of the solution obtained by adding 15 g of silver chloride to 50 cm^3 of distilled water. (STP)

CT2. Calculate the volume of hydrogen formed in the reaction of 6.35 g of copper with the corresponding amount of sulfuric acid. (A_r(Cu)=63.5; A_r(H)=1; A_r(S)=32; A_r(O)=16) (STP)

CT3. What is the pH of a solution formed by the addition of 0.1 mol of aluminum to a 10 dm^3 of water? (A_r(Al)=27) (STP)

CT4. How many grams of barium sulphate should be added to 150 g of distilled water to prepare a 10% solution (A_r(Ba)=137) (STP)

CT5. What is the volume of carbon needed to react with the appropriate amount of oxygen to produce 2.24 dm^3 of carbon dioxide? (A_r(C)=12; A_r(O)=16) (STP)

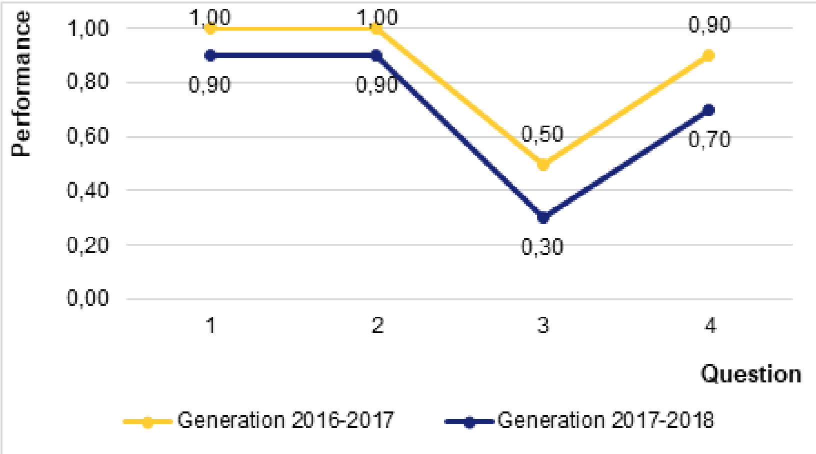
Testing was conducted in 4 phases: (i) February 2017 (T1, generation 2016-2017), (ii) March 2017 (T2, generation 2016-2017), (iii) February 2018 (T1, generation 2017-2018) and (iv) March 2018 (T2, generation 2017-2018). Time for solving T1 and T2 was unlimited, and all the tests were carried out anonymously. Data processing was carried out in the program Microsoft Office Excel.

Research Results

Results of T1

Figure 1 shows the T1 results for both generations of students. Based on the results, it is evident that students in a very high percentage were successful in solving the first, second and fourth questions, which were related to the recognition of compounds and metals insoluble in water and the molar volume of gases. The lowest achievement was accomplished in the third question, where SO_2 was expected to be recognized as a product in the reaction of copper and concentrated sulfuric acid. High achievements on T1 questions were expected, as students were in their final year which means they had the expected declarative knowledge with certain exceptions (Q3). Such results were a precondition for the next stage of research, that is, for conducting T2.

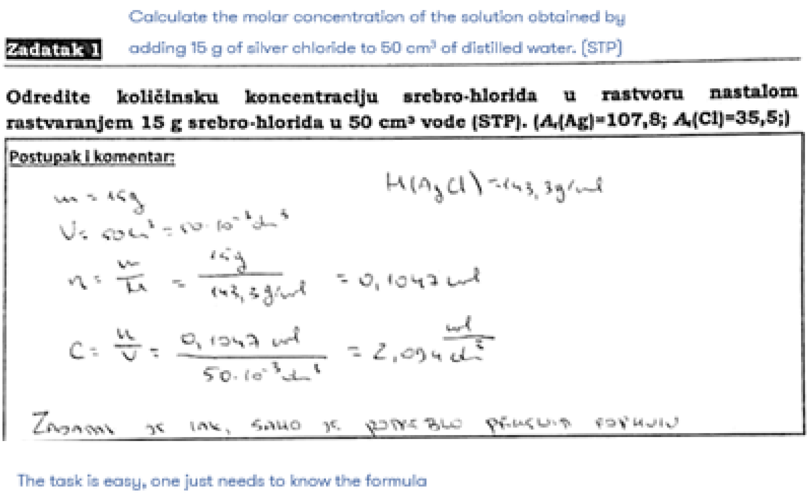
Figure 1
Achievements on T1



Results of T2

The results of T2 will be analysed qualitatively on the selected examples of tasks. In CT1, students were asked to calculate the molar concentration of silver chloride in the solution formed by its dissolution in water. Although by solving Q1 on T1 students showed that they know that silver chloride has low solubility in water, in CT1 they ignored this information. All students in this study tried to respond to the request of the task by applying a standard formula for calculating the molar concentration of a solution, and none of the students noticed the deceptive information. Figure 2 shows an example of a student's response.

Figure 2
An Example of a Student's Response on CT1



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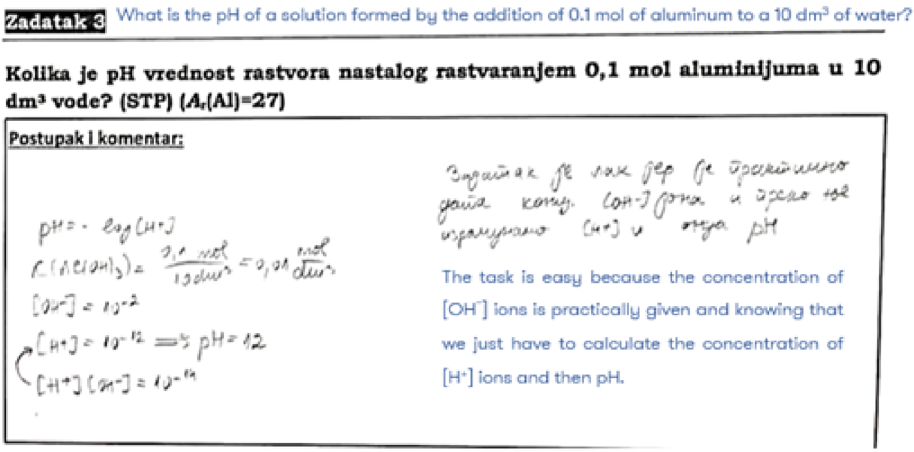
In CT 3, it was necessary to calculate the pH value of the solution, which is formed by dissolving aluminum in water. In this task, the students did not pay attention to the key information - aluminum that does not dissolve in water. Surprisingly, none of the respondents linked the insolubility of aluminum in water with its application in everyday life, for example in the production of aluminum packaging used for storing foods such as milk, yoghurt and other products with a high percentage of water in their composition. On the other hand, the students were very successful in solving Q2 where they recognized aluminum as a water-insoluble metal. This means that students have declarative (factual) knowledge, but that this knowledge is rather passive. An example of a student's response on CT3 is provided in Figure 3.

Figure 3
An Example of a Student's Response on CT3



In CT5, it was necessary to calculate the volume of carbon, however, since carbon is an element in a solid-state under STP, it was not possible to calculate its volume using only the data given. The students overlooked this fact and performed the calculation assuming that the volume of 1 mole of carbon is 22.4 dm^3 as if the carbon under STP is a gas (figure 4). As with the previous questions on T1, the students were successful in solving Q4 where they showed that they knew that the value of 22.4 refers only to gases. However, this knowledge was not applied in CT5, which once again confirmed that when solving quantitative problems, students give preference to algorithms over logical reasoning.

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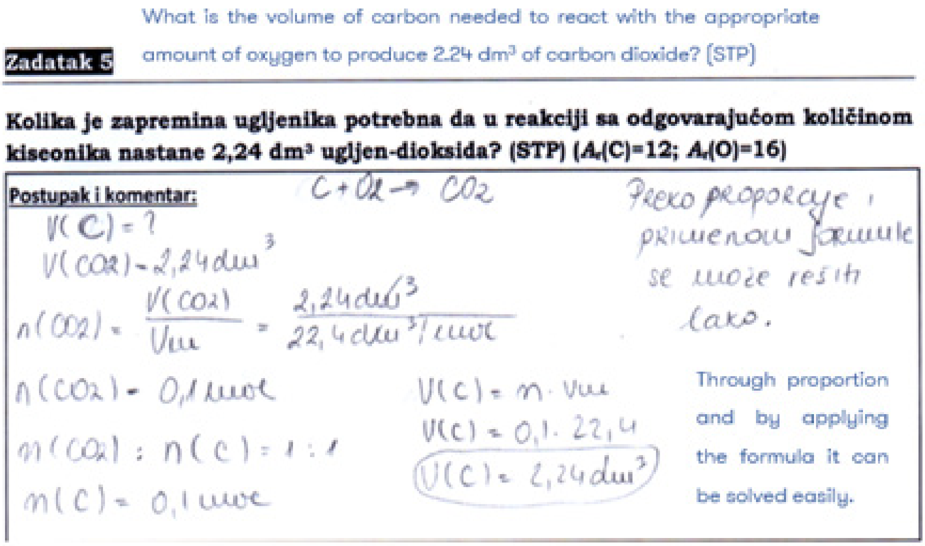
Figure 4
An Example of a Student's Response on CT5



Analysis of Students' Comments

As can be seen in Figures 2, 3 and 4, students were expected to give a brief comment on each CT related to the solving procedure. Students were instructed to provide a comment in a blank field reporting on how difficult or easy it was to resolve a task. Additionally, they were asked to reflect on each CT; whether the request was clear and logical to them, or they found some information missing, misleading etc.

Selected comments:

- The task is easy, one just needs to apply the formula.
- The task is easy if you know the formula.
- The task is not a problem if the formulas and the value of V_m are known.
- The task is easy because the concentration of [OH^-] ions is practically given and knowing that we just have to calculate the concentration of [H^+] ions and then pH.
- Extremely easy because one just needs to substitute known variables into the formula.
- The task is easy because by applying the formula it can be solved in one step.

- I can't remember the formula.
- I'm not sure if I used an appropriate formula.
- The task is not difficult, but I can't recall the formula.
- I forgot the exact formula. I think it's easy, but I can't remember the formula I need to apply.
- I can't calculate, because I haven't used that formula for a long time.

What all comments have in common is the word formula. Most of the students were very confident that they resolved the tasks correctly because they knew the appropriate formula. From their comments it is clear that they apply an algorithmic approach – they read the text of the task, extract the data, write the appropriate formula and substitute known variables into the formula. At the same time, they do not pay enough attention to the meaning of the requirements.

Conclusions

Based on the results of T1, it can be concluded that students had certain declarative knowledge. All students who tried to resolve the tasks from T2 were using known formulas and algorithms. None of the students noticed the concepts that made the calculation nonsensical. Based on the comments, it can be concluded that students do not pay enough attention to the underlying concepts.

These results suggest that more attention should be paid to the conceptual underpinnings and less to a drill that is based on solving a large number of calculations by mechanical learning of steps and by rote memorization of procedures. Students must understand the meaning of calculations and their relation to everyday life. For this purpose, it is convenient that tasks contain an everyday life context that will enhance student motivation, thus enabling the acquired knowledge to be long-term and more functional.

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Declaration of Interest

Authors declare no competing interest.

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