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Using Simulations to Detect Difficulties in the Process of Learning “Chemical Solutions”

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Abstract Using animations, visualizations and simulations is a common practice to teach chemistry. These didactic resources provide a motivational effect which in turn should improve the understanding of concepts by the students. This is effectively observed, but not all students benefit from these resources to the same extent. In this work, we use a simulation of chemical solutions and then evaluate a group of students on it. From the wrong answers we proceed to establish categories: 1) Incorrect or misguided mathematical approaches, dissociated from the chemical meaning of the question, 2) difficulties in the use of chemical syntax, 3) semantic difficulties, and 4) alternative mental models. Having identified the types of errors allows teachers to work on them in a directed manner, making possible different approaches for each category.

Keywords: *simulations, chemical solutions, teaching, learning, errors*

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1. Introduction

Animated simulations of chemical processes for teaching purposes have been known for decades, and their didactic use has been widely recommended. For example, Talanquer [1] argues that "using teaching tools of this kind in the classroom has a positive impact both in the understanding of fundamental scientific concepts and in the development of reasoning skills". And, in fact, in general, didactic research shows that the use of information and communication technologies (ICT) allowing interaction or construction and interaction with models in the classroom has very positive results [2,3].

Simulations have a great potential to improve the learning process at higher level education. It can be adapted to suit the pace, interests and talents of each individual student in the context of virtual environments [4]. For example, the set of online simulations known as PhET (http://phet.colorado.edu/) is an archetype of resources designed to involve the students in the exploration of properties and behavior of pre-modeled systems [5].

However, it has been noticed that even when following all the didactic guidelines for the use of these simulations, not all students take advantage of this teaching tool. It is worth to investigate the variables that are blocking the incorporation of some central concepts in chemistry: in our case, solutions.

According to many curricular guidelines in Spanish speaking countries [6], the elementary concepts to understand what is a solution, its properties, and how they are measured and modified, are taught in the first few chemistry lessons in high school. These central concepts constitute a fundamental core to develop further topics in the area. Chemical solutions is considered a basic subject and is repeatedly evaluated before college, however, serious difficulties have been found [7,8]. Taking into account these topics, the objective of this work was focused on investigating what might be the variables that hinder learning the theme "Solutions" using ICT.

2. Methodology

2.1. Actors

A sample of 197 students from eight different courses of Chemical subject of the first year of studies at the University of Buenos Aires was taken. All students who participated did so voluntarily and anonymously during one semester.

2.2. Description of the Experience

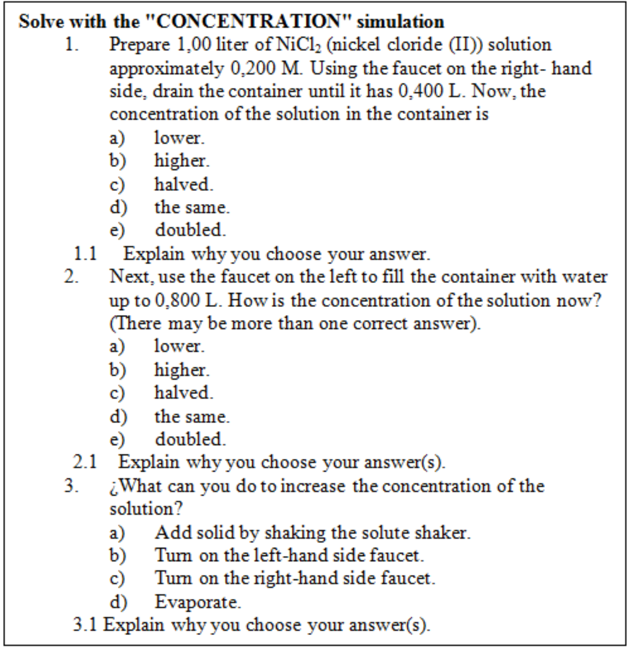
The topic "Solutions" was taught in two classes of three hours each. In all courses, the PhET "Concentration" simulation was used to explain how varying concentrations of a solution by adding or removing solvent or solute. Student participants were asked to respond a questionnaire based on the aforementioned simulation. The responses were analyzed and grouped into categories referring to the various misconceptions found.

In the virtual campus available to the subject, in the module dedicated to "Solutions", simulation "Concentration" and the *ad hoc* questionnaire were imbibed. Students were asked to answer the questions and were informed that responses would be examined but not qualified.

2.3. Questionnaire

The questionnaire (Box 1) consisted of three multiple choice questions with justification. The first question surveyed the students' grasp of the concept of homogeneous phase. It included chemical language (molarity sign M and chemical formula symbolic expression) and it expected the students to apply conceptual reasoning rather than numerical calculations. The second question covered the concept of dilution and it only indicated volumes. The third question involved “concentrating solutions” at a conceptual level, without any mathematical notation.

Box 1. Questionnaire used in the experiment



Solve with the "CONCENTRATION" simulation

1. Prepare 1,00 liter of $NiCl_2$ (nickel cloride (II)) solution approximately 0,200 M. Using the faucet on the right- hand side, drain the container until it has 0,400 L. Now, the concentration of the solution in the container is
   a) lower.
   b) higher.
   c) halved.
   d) the same.
   e) doubled.

1.1 Explain why you choose your answer.

2. Next, use the faucet on the left to fill the container with water up to 0,800 L. How is the concentration of the solution now? (There may be more than one correct answer).
   a) lower.
   b) higher.
   c) halved.
   d) the same.
   e) doubled.

2.1 Explain why you choose your answer(s).

3. ¿What can you do to increase the concentration of the solution?
   a) Add solid by shaking the solute shaker.
   b) Turn on the left-hand side faucet.
   c) Turn on the right-hand side faucet.
   d) Evaporate.

3.1 Explain why you choose your answer(s).

2.3. Data Analysis

For each question, all answers were subjected to the analysis qualitative logic named Constant Comparative Method [9,10,11]. All answers to each question were read carefully, compared to one another and temporarily assigned to provisional categories. These categories were based both in the content and in the students' approach to the answers. Further analysis of the students' explanations led to the redefinition and modification of the answers groups and, accordingly, the re-classification of answers. Once all answers were classified, they were read again to guarantee the coherence of each group and category definition. This process resulted in redefining and improving the categories and the reclassification of some answers. The procedure was applied iteratively until a consistent and coherent set of groups was obtained for all three sets of answers.

The reliability of the refined categories was verified by an independent researcher who was asked to classify 25% of the answers chosen at random, getting over 90% agreement for each of the three groups.

3. Results and Discussion

3.1. Answers to Question 1

71% of the students (141) answered correctly that the solution concentration stayed the same (option "d"). The wrong answers (29%) had the following distribution (Table 1).

Table 1. Number and percentage of each wrong answer to Question 1

Chosen answer Distribution	is lower	is higher	is halved	is doubled
Number of answers	33	19	3	0
Percentage	17%	10%	2%	0%

Wrong justifications were classified considering the following interpretations:

1) Those who answered (a) or (c) ("is lower, and "is halved) seem to have mistakenly assumed concepts like "concentration", "volume" and/or "solution" as synonyms.

Examples:

Student 1: *"It is lower because the container is emptied and the concentration decreases."*

Student 2: *"Emptying the container causes a lower concentration."*

Student 3: *"It is lower since there are less liters of solution therefore the concentration of the solution will be lower"*

2) For answers (b) and (e) ("is higher" and "is doubled"), the source of the mistake could be alternative mental models. We could observe that in this case the students were making a wrong interpretation of the physical situation; they probably thought the solute, being a solid, would stay at the bottom of the container, not flowing causing the solution to concentrate when the solvent was drained.

Examples:

Student 4: *"Because there is the same amount of solute but in a lower proportion of solvent in the solution."*

Student 5: *"Because extracting the solvent from the container makes the solute more concentrated, since it will become more intense."*

These type of responses may correspond to the problem of false proportionality concerning cases as “more A-more B”, known as the “intuitive rules theory” [12].

3.2. Answers to Question 2

77% of the students (159) answered this question correctly. The distribution of the 23% of wrong answers was as follows (Table 2).

Table 2. Number and percentage of each wrong answer to Question 2

Chosen answer Distribution	is lower	is higher	is doubled
Number of answers	15	9	12
Percentage	9%	6%	8%

We interpret that for the cases where the answers "is higher" or "is doubled" were chosen, the mistake was due to:

1) Taking the concepts "concentration", "volume", "solution" and/or "solvent" as synonyms. According to these answers, if the volume increased, then the concentration increased as well, at the expense of adding solvent or solution (any liquid).

Examples:

Student 6: *"Because more liquid was added."*

Student 7: *"Because you're adding water and then the concentration is higher."*

Student 8: *"Because there is an increase of the solvent."*

Student 9: *"Because there is more solution"*

2) Incorrectly using mathematical algorithms learned in class. There was a tendency to use maths without taking into account the chemical meaning of the implemented operations.

Examples:

Student 10: *"I used the Rule of Three!*
If
0.0800M ---- 0,400L
x -------------- 0,800L
Hence
x = 0,16M
then, dividing 0.16 M gives 0.0800 M and well, that's twice as much!"

Student 11*: "It is higher, it is doubled:*
If
0.400 L ----- 0.0800 M
0.800 L ----- 0.160 M"

In these cases, the calculation refers to the number of moles, and the student writes "M", that is "molarity" in chemical notation, a concentration unit.

We found the "is the same" answers to be wrong because:

1) They took some sentences used in class and gave them such importance that they applied them to any situation.

Examples:

Student 12: *"The amount of solute is the same despite the increase in the amount of solution."*

Student 13: *"It is the same because it never changes, even if water is added."*

Student 14: *"Because it is just volume that is added, the concentration stays the same."*

2) They used mathematical operation without taking into account the chemical meaning. They checked that the numbers matched regardless of the relation those numbers may have.

Example:

Student 15:
"1.00 mole solute ------------------- 130 gr solute
0.200 moles solute ---------------x = 26 gr solute
26 gr solute ------------------1000 cm^3 solution
***2.6 gr solute** = x -------------100 cm^3 solution*
0.200 moles solute --------------- 1000 cm^3 solution
0.16 moles solute = x ---------- 800 cm^3 solution
1 mol solute ---------------------- 130 gr solute
0.16 moles solute----------- x = 20.8 gr solute
20.8 gr solute----------------800 cm^3 solution
***2.6 gr solute** = x--------------100 cm^3 solution"*

3.3. Answers to Question 3

85% of students (168) answered this question correctly. The 15% wrong answers had the following distribution (Table 3).

Table 3. Number and percentage of each wrong answer to Question 3

Chosen answer Distribution	Turn on faucet on the left	Turn on faucet on the right
Number of answers	12	17
Percentage	6%	9%

Again, it would look like those students answering "Turn on the faucet on the left" took the terms "concentration", "solution" and "volume" for synonyms; and at the same time they mistook solute and solvent.

Examples:

Student 16: *"If the amount of solvent is increased, the number of moles of solute will also increase and the concentration will be higher."*

Student 17: *"Because this faucet increases the water therefore there will be more solution."*

Student 18: *"I chose this option because we are adding more concentration."*

Student 19: *"If we add H_2O the concentration of the solution will increase."*

The students that answered "Turn on the faucet on the right" refer to the solvent "flowing" and the solid being held in the container when the faucet is turned on.

Examples:

Student 20: *"I would turn on the faucet on the right to lose part of the solvent and make the concentration higher."*

Student 21: *"Because removing water increases the concentration."*

Student 22: *"When I turn on the faucet on the right, I am taking solvent from the container, then the solute stays the same and will be more intense. And the concentration will increase."*

4. Conclusions

When we started this experience we were expecting that the use of the simulation helped the students learn the concepts related to solutions. We have found that a high percentage of the students used and took advantage of the tool. However, the use of the simulation does not seem to have had a positive effect in a small minority of students, whose answers were classified according to the kind of errors we found:

1) Incorrect or misguided mathematical approaches, dissociated from the chemical meaning of the question: these answers are given by students that approach chemistry questions as if they were mathematical problems; they have not grasped the chemical notions that should guide their resolution. For them, chemistry problems are solved in a numerical fashion, ignoring the units involved. The idea of value of a physical magnitude is lost, in favor of abstract numbers.

Numerical calculations are historically central to chemistry problems. In 1858, Stanislao Cannizzaro, a leading Italian chemist, showed his skeptical students the importance of math calculations to determine atomic and molecular masses. Since then, solving mathematical problems became one of the main activities of chemistry teaching, spreading the notion across the 20th century that being a chemist requires the ability to do numerical calculations [13].

The theory of the intuitive rules was introduced by Tirosh and Stavy [14] for analyzing and predicting individuals' erroneous solutions to mathematical and scientific problems. This theory states that when solving tasks with external similarities but conceptual diversity, students tend to work with a limited number of intuitive rules, even when the tasks require a different type of reasoning and belong to separate content areas.

The intuitive rules theory has been proposed both as an explanatory and predictive tool. It's been observed to offer a good structure to analyze student's answers to a wide variety of mathematical problems and it has been proposed for educators to predict students' misconceptions.

Intuitive rules are global and coercive. Students are confident in their reliance on them, and they are used even after undergoing formal learning. This highlights the value of promoting critical thinking; since, according to this theory, wrong reasoning are often caused by external or cursory factors.

The automatism caused by the requirement to use all provided data is stressed by the assumption that "the teacher will never give them problems in which some data is not strictly necessary"[15].

The kind of automatism leading to such errors, says Peralta [15], grows with the students' age. This calls for consideration of the negative influence of formal education on this kind of skills, and the awareness of physics and chemistry teachers.

2) Difficulties in the use of chemical syntax: in these answers, the students misapply the units representing expressions of concentration. It is observed the confusion in the use of moles and molarity.

The concentration of a solution (and intensive property) is the ratio of two extensive properties, the mass of the solute and the volume of the solution.

These variables may be analyzed separately but they must be interpreted together. Thus, for a given volume of solution, the concentration is directly proportional to the mass of solute and inversely proportional to the volume of it.

"Some evidence suggests that young students tend to assume that changes in a system are caused by a single active agent [...] they are prone to structure and analyze the evolution of a system as a linear chain of events where each variable involved is considered one at a time, and there is a single favored evolution of the process".

According to several authors, this students' simplistic model is responsible for many conceptual difficulties [16].

3) Semantic difficulties: in this category were included the answers that conflate different chemistry concepts, rendering them indistinguishable. Semantic errors [17] originate from confusing words' connotations. In our case, we call them "errors in chemical semantics" when there is at least one swap of non-synonym terms' meanings: solution, solute, solvent; concentration, density, molarity; or dissolve, dilute, mix. It is worth clarifying that students can confuse the terms solvent and solution because the added solvent leads to increase the volume of the solution.

4) Alternative mental models

Upon arriving at the classroom, students bring a variety of mental models they will resort to try to understand the classes they attend, the texts they read, etc. [18].

In the answers based on these models, the explanations show reasoning based on conceptual interpretations not scientifically validated. When students enter university, they have personal perceptions of how they believe the world works. Probably the limitations of the simulation do not favor the possibility of producing a conceptual change. A solution is a homogeneous system consisting of at least two substances. This simulation represents macroscopically a system of this type. However, the student does not consider the dissolved particles when analyzing the variations in the concentration of the solution when the volume thereof to slopping.

It was noticed that all participant students had studied the subject and had engaged with the simulations, and all of them passed the subject. Even when the identified errors appeared in a minority of students, we are concerned that these deficits could be sustained through their degrees, hindering their future performance. It is therefore appropriate to consider that the teacher's duty must focus on search a common language between the students' mental representations and the discipline-specific concepts established by the current scientific paradigm. At the same time, having identified the types of errors made by college students allows teachers to work on them in a directed manner, making possible different approaches for each category.

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References

[1] Talanquer, V., Simulaciones computacionales para construir y explorar modelos [Computer simulations for building and exploring models]. *Alambique*. 76, 8-16, Jan 2014. Available: https://sites.google.com/site/talanquerchemed/publications. [Accessed Dec. 10, 2015].

[2] Adams, W. K. Paulson A. and Wieman C. E., "What Levels of Guidance Promote Engaged Exploration with Interactive Simulations?" in *2008 PERC Proceedings, Edmonton, Canada*, 1064: 59-62, 2008. Available: http://scitation.aip.org/content/aip/proceeding/aipcp/1064. [Accessed Nov. 4, 2015].

[3] Bell, R.L. and Smetana, L.K., "Using computer simulations to enhance science teaching and learning", in Bell, R.L.; Gess-Newsome, J.; Luft , J. (Eds.), *Technology in the secondary science classroom*, Washington, D. C. National Science Teachers Association Press, 2008, 23-32.

[4] Honey, M. A. and Hilton, M. (eds.), *Learning science through computer games and simulations*. Washington, DC, The National Academies Press, 2011. Available: http://www.nap.edu/openbook.php?record_id=13078&page=25 [Accessed Dec. 10, 2015].

[5] Wieman, C. E. and Perkins, K. K., "A powerful tool for teaching science", *Nature*, 2, 290-292, May 2006.

[6] Nappa, N., Insausti, M. J., Sigüenza, A. F., "Características en la construcción y rodaje de los modelos mentales generados sobre las disoluciones", *Rev. Eureka. Enseñ. Divul. Cien*., 3(1), 2-22, Jan 2006. Available:http://venus.uca.es/eureka/revista/Volumen3/Numero_3_1/Nappa_et_al_2006.pdf [Accessed Nov. 4, 2015].

[7] Barker, V. Beyond Appearances: Students' misconceptions about basic chemical ideas. A report prepared for the Royal Society of Chemistry
Available:
http://modeling.asu.edu/modeling/KindVanessaBarkerchem.pdf
[Accessed May 7, 2016].

[8] Smith K. J. and Metz P. A. Evaluating Student Understanding of Solution Chemistry through Microscopic Representations. J. *Chem. Educ*., 73 (3), 233-235, March 1996.

[9] Glaser, B.G., *Theoretical Sensitivity: Advances in the Methodology of Grounded Theory*, Mill Valley, CA, The Sociology Press, 1978, 25-96.

[10] Miles, M. B. and Huberman, A.M., *Qualitative data analysis: An expanded sourcebook* (2nd ed.), Thousand Oaks, CA, Sage, 1994.

[11] Sirvent, M.T. "Cuadro Comparativo entre Lógicas según dimensiones del Diseño de Investigación", In: *El Proceso de Investigación. Investigación y Estadística I* (2nd. Ed.). Buenos Aires, Cuadernos de la Oficina de Publicaciones de la Facultad de Filosofía y Letras (Opfyl), 2003, 9-38.

[12] Van Dooren, W; De Bock, D.; Weyers, D and Verschaffel, L.The predictive power of intuitive rules: A critical analysis of the impact of `more A–more B' and `same A–same B'. *Educational Studies in Mathematics*, 56: 179-207, July 2004.

[13] Izquierdo, M., ¿Para qué se inventaron los problemas de Química?, *Educación Química*, 16 (2), 246-259, April 2005. Available: http://educacionquimica.info/busqueda.php/ [Accessed Dec. 10, 2015].

[14] Tirosh, D. and Stavy, R. Intuitive rules: A way to explain and predict student’s reasoning. *Educational Studies in Mathematics*, 38, 51-66, March 1999.

[15] Peralta, J., "Sobre los automatismos en la resolución de problemas", *Boletín de la Asociación Matemática Venezolana*; 13 (1), 87-103, 2005. Available: http://www.emis.de/journals/BAMV/conten/vol12/jperalta.pdf/ [Accessed Nov. 10, 2015].

[16] Talanquer, V., "Exploring dominant types of explanations built by General Chemistry students", *International Journal of Science Education*, 32 (18), 2393-2412, Dec 2010.

[17] Astolfi, J. P., *El error, un medio para enseñar*, Sevilla, Díada Editora, 2003, 11-78.

[18] Bain, K., *Lo que hacen los mejores profesores universitarios*, PUV, Valencia, 2007, 1-128.