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COLLABORATIVE ACTIVITIES FOR SOLVING MULTI-STEP PROBLEMS IN GENERAL CHEMISTRY

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Abstract

The learning of solving multi-step problems is a relevant aim in chemical education for engineering students. In these questions, after analyzing initial data, a complex reasoning and an elaborated mathematical procedure is needed to achieve the correct numerical answer. However, many students are able to effectively use algorithms even with a lack of meaningful understanding of involved chemical concepts. This paper reports the application of some collaborative actions in order to induce a complete acquisition of problem solving skills. The studied approaches, performed inside and outside the classroom, are classified in low-collaborative and high-collaborative activities, depending on the relative participation of instructor/students in their development. The critical description of the proposed methodology and the produced outcomes are exposed. The contribution of each major reasoning mode (model, rule or case based) employed in these activities is analyzed. Also, the perception of students is evaluated on the basis on the data provided by direct observation and a specific survey with Likert-scale and open-ended questions. The results indicate that the changes of teaching to a more conceptual orientation lead a deeper understanding, minimizing misconceptions or a rote learning.

Keywords – Problem solving skills, collaborative activities, Teaching-learning methodologies.

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1 INTRODUCTION

The learning of solving numerical problems mainly involves both conceptual and algorithmic components, together with a heuristic approach for a global strategy. The first is related to the understanding of underlying concepts from the basic theories of science, while the second is related to mathematical procedures for applying specific equations. So, the general algebraic system is at the heart of advanced modern calculation techniques in engineering (Lee, 2003). During the teaching and assessment of chemistry, as other sciences, the instructors must design and prepare activities, materials, and other educational resources for guaranteeing that the engineering students should be able to learn both contributions.

Several authors have demonstrated that students might exhibit different behaviors answering chemistry questions (Bodner, 2003; Talanquer, 2006; Taber & Bricheno, 2009; Taber & García-Franco, 2010). This variety of alternative conceptions is a result of applying a set of more or less integrated cognitive resources that guide but also constrain their answers. In a linear diagram of cognitive capabilities, the students can be classified from conceptual learners to algorithm learners. The students at the first end fail in the algebraic manipulation of mathematical formulae, although they understand the theoretical background of the question. The last end corresponds to students that are able to successfully apply algorithms even in the absence of meaningful conceptual understanding.

The involved levels of cognitive processing and the common questions proposed in chemistry subjects have been examined by several educational researchers. A relevant study is the investigation of Zoller, Dori and

Lubezky (2002), classifying chemistry questions in lower-order cognitive skills (LOCS) and higher-order cognitive skills (HOCS). Smith, Nakhleh and Bretz (2010) reviewed the published categorizations of chemistry questions. This study also suggested that a useful framework for conceptualizing existing results is the revised Bloom's taxonomy.

Different models of reasoning are triggered when a student is solving questions (Kraft, Strickland & Bhattacharyya, 2010; Christian & Talanquer, 2012). Major modes are model-based reasoning (MBR), case-based reasoning (CBR), and rule-based reasoning (RBR). MBR is an abstraction to understand matter at different scales following conceptual/mathematical approaches. CBR may imply using old solutions or experiences to interpret or explain new situations and solve a less familiar task. RBR involves inducing patterns of behavior from direct experience, and then the questions are solved based on generally forward-working schemes associated to each specific framework.

Several studies in chemical education have been focused on looking for teaching methods (Dori & Hameriri, 2003). The description of algorithm to get the correct answers is the main objective in conventional teaching. In this sense, some teachers often prefer expository methods - presentation of a nearly closed strategy -, rather than those related to the use of an elaborated judgment by students. The teacher can control the reasoning mode and direct the students through the algorithm. The students' attention can be focused on the key points to solve the question. But, active learning methods appear to produce an improved learning environment leading to increased student satisfaction, and even, better academic performance (Kovac, 1999). Then, the revised conceptions of problem solving need a transformation from routine tasks to an attractive and valuable assignment. Changes from some instructional practices based on teacher-controlled activities to ones grounded in student-controlled activities are required. The application of various methodological resources is especially recommended for novel engineering students, because that should provide a solid background for more specialized subjects. A shift of chemistry instruction is needed from an algorithmic orientation to a more conceptual orientation.

The central goal of this study was to investigate the integration of collaborative activities in teaching in order to induce a deeper learning and increasing the success in solving chemical questions. In particular, the investigation was guided by how to modify instruction to better support students' reasoning inside and outside the classroom. The proposed approach was based on multi-step questions that involved both algorithmic and conceptual orientations requiring more advanced levels of cognitive processing. Also, a collaborative learning was a key strategy for facing to complex multi-step questions. Two or more peers working together on learning activities was the best tool for participants actively involved in conceiving and internalizing the solving knowledge and skills.

2 DESIGN/METHODOLOGY/APPROACH

2.1 Participants

This study was conducted in Universitat Politècnica de Valéncia, a public technological university in the western Spain. Participants were Agriculture Engineering students enrolled in General Chemistry (first year course, first semester). The methodological changes were performed during two consecutive academic courses. The number of students enrolled in the subject was 184 (2012-2013) and 170 (2013-2014) divided in three groups supervised by a teacher each one. Only a group participated in the entire innovative experience, the number of students being 64 (2012-2013) and 44 (2013-2014).

2.2 Rubrics

Information from the students enrolled in previous courses was also analyzed (surveys, observation notes, reports, exams). A rubric was elaborated to determine the reasoning models and common errors performed by students during the solving of chemical questions. Representative paper-based evidences were collected during the entire development of teaching-learning process in the last years. Then, the teacher categorized issues such as initial reasoning, discussion style during collaborative activities, reasoning language, or use of drawings. Following the criteria of the rubric, the assigned values were from 1 (lowest level) to 5 (highest level). The errors were classified as related to mathematical skills, scientific skills, chemical skills, and handling of units.

2.3 Activities

The actions focused on the learning of solving problems were integrated in the development of the subject. These activities corresponded to about 40 % of course time. Designed strategies for the interactive solving of relevant problems were divided in low-collaborative and high-collaborative activities. The first category included complete group to self-learning or peer-learning actions. The second category is composed by activities performed in pairs or small groups for the solving of proposed questions. The main resources were textbook, blackboard, multimedia slides, and multimedia material obtained from the Internet. The textbook was composed by 450 multi-step questions and 200 short questions. Each unit contained solved problems and unsolved problems with solutions (Herrero, Atienza, Noguera & Tortajada-Genaro, 2008).

Table 1 summarizes the applied activities with time distribution, participation, and resources used. Most activities were performed for all students enrolled in the subject. Nevertheless, an increment of high-collaborative activities (about 20 %) - decreasing the number of low-collaborative actions - was promoted in the participant group. Also, inquisitory style was the predominant in the lectures, compared to expository style of the other groups.

	Low-collaborative activities		***High-collaborative activities***	
	Collaborative lectures	***Off-class activities***	***Off-class group activities***	***Presence group activities***
Actions	*Expository and inquisitory*	*Textbook and internet problems*	*Induced tasks and self-regulated tasks*	*Group tutorials and specific seminars*
Example	*Induced discussion during the presentation of a new question*	*Resolution of a list of representative problems*	*Resolution of a selected problem by 2-4 students before a deadline*	*Supervised resolution of a selected problem*
Time distribution	*Initial phase*	*Continuous*	*Medium phase*	*Medium-Final phase*
Participation	*Teacher controlled*	*Self-learning Supported learning*	*Group off-class learning*	*Group learning Student-teacher*
Resources	*Schemes for solving problems Interactive solving of relevant problems*	*Complete/Partial solved problems Unsolved problems Conceptual questions*	*Selected unsolved problems*	*Interactive resolution of relevant problems*

Table 1. Studied collaborative activities for learning question solving

2.4 Survey

The perception of innovative experience was collected by Likert-scale and open-ended questions (see Fig 1). The survey was anonymously filled up in the last lecture of the course, after a short explanation performed by instructor. First question was related to the cognitive capabilities and students had to classify themselves the kind of learner, from conceptual learner to algorithm learner. In the following questions, the students evaluated the contribution of different methodologies available to learn how solving multi-step problems. Finally, an open-ended question allowed them a comment about teaching quality and development of subject.

General Chemistry

UNIVERSIDAD POLITECNICA DE VALENCIA

SURVEY ABOUT SOLVING PROBLEMS

Objective: Determine the opinion of students about the learning strategies for problem solving in General Chemistry.

Question 1. Classify on the following scale of cognitive abilities, depending on the strategy that you use in solving problems. Option A corresponds to a student is able to apply the resolution algorithms without understanding fully the conceptual level. Option E corresponds to students who understand the theoretical background of the problem but usually fail in algebraic manipulation of mathematical formulas.

A Algorithm	B Predominant Algorithm	C Algorithm-Conceptual	D Predominant Conceptual	E Conceptual

Question 2. Evaluate the impact of the strategies that have been used on your learning in solving problems (0: none - 10: a lot).

1	Conventional lecture (expository)	
2	Innovative lecture (inquisitive)	
3	Reference textbook.	
4	Other books	
5	Internet resources	
6	Collaborative activities	
7	Study groups	
8	Group tutorials	
9	Seminars	

Question 3. Indicates the time spent for each of the following activities

1	Revision of class notes	hours / week
2	Revision of solved problems	hours / week
3	Solving new problems	hours / week
4	Study	hours / week

Question 4. Select the six major limitations hinder you learning problem solving, ordered from high to low limitation.

A	Teaching style	K	Chemical background (prerequisite courses)
B	Rate of class development	L	Mathematical background
C	Attitude of classmates	M	Theoretical concepts
D	Group coordination	N	Understanding of problem statements
E	Availability of material/resources	O	Initial approach to the problem (initial sketch)
F	Lack of interest/motivation	P	Language and chemical formulation
G	Available time for studying	Q	Conversion between macroscopic, atomic and symbolic level
H	Time management	R	Management units and conversion
I	Personal problems	S	Using the Calculator
J	Others:	T	Result checking

Question 5. Comment the methodology used for problem solving. Add other comments if necessary:

Figure 1. Survey about solving problems

3 RESULTS

3.1 Analysis of reasoning models and common errors

The first step was the analysis of the rubrics generated from the paper based evidences collected in the last years. The reasoning strategies and errors performed by students during the solving of chemical questions were determined.

In the first part of rubrics, the contribution of major modes of reasoning applied to solving quantitative chemistry problems (MBR, CBR, and RBR) was studied. The results indicated that a mixture of CBR and RBR was the mode of reasoning commonly displayed in the observed study groups. Students applied normative, empirical, or theoretical rules extracted from some examples as the main approach to solve a problem. The process started with the search of keywords in the statement, for instance the students underlined some relevant words or data. These chemical terms, equations, units or numeric data allowed students to establish a pattern for comparing with similar multi-step questions. A linear, forward-working, and rational manner was applied following empirical generalization. An example was that students included words as “step 1”, “step 2”, etc. These rules served as heuristics to detect relevant information, and make quick predictions and decisions. This type of reasoning was quite efficient in generating satisfactory answers with low cognitive effort and processing time. Unfortunately, the indiscriminate application of rules across many situations yielded systematic errors and reasoning biases. For instance, novices often failed to recognize new situations that justified the use of other approach and tended to overextend the application scope of a given rule.

In the second part of rubrics, the types of mistakes students made were analyzed. General limitations were identified allowing the categorization of common difficulties or mistakes (mathematical errors, scientific errors, chemical errors, and handling of units). These errors reflected the sources of difficulties that students encounter in chemical questions. An obvious correlation found was that the success rate of the in solving multi-step problems decreased as the problem difficulty increased. Data showed that the most frequent errors were related to required mathematical skills and the lack of a deep understanding of concepts. For instance, the problem was not completed because they did not solve a second order equation. Also, an incorrect relation among concepts and their quantitative aspects was observed. Hence, some students were unable to correctly solve due to their limitations in a general level (scientific) or a specific level (chemical).

As it has been described in several research studies, the quantitative aspect of chemistry is often an obstacle for freshmen in an introductory college course of chemistry (Dori & Hameiri, 2003). The performance of student achievement was significantly dependent on the mathematics level. Mathematical skills required throughout a chemistry course mainly involve simple algebraic methods. But, students showed important problems to rearrange an algebraic equation to solve for an unknown variable or incognita. The following category was composed by deficiencies in general skills related to scientific tools or methods, such graphical data, conversion within metric system, or scientific notation. In the area chemistry skills, the most frequent student faults agreed with those previously described (Lee, 2003). They included from incorrect names for quantities to procedure skills, such chemical language or stoichiometric relationships. Students in their first year of University had a hard time finding the connection between macroscopic, sub-microscopic, and symbolic levels, as it was observed for several researchers (Dori & Hameriri, 2003). Finally, students often found difficulties in the handling of units, the common errors being noninclusion, incorrect conversions, and dimension heterogeneity. In conclusion, student deficiencies in numerical and scientific skills detected in this study were the same as those widely recognized among the engineering disciplines.

The analysis of reasoning models, levels of cognitive processing and common errors allowed us to design a more productive instruction, in terms of teaching successful strategies to solve questions.

3.2 Studied strategies for teaching how solving multi-step chemical questions

Different strategies were introduced in this General Chemistry course to promote the collaborative acquisition of effective skills for solving multi-step questions. The goal was to get the student to solve problems in a rational manner and not only mechanically.

3.2.1 Collaborative lectures

An increment of student participation was applied. Expository and inquisitory presentations were selected as model of teaching to engage students in discovering rules and relationships of the subject area. The role of the teacher was shifted from presenting the algorithm for solving problems to activating conversation with the students to encourage them to discover the answers. This approach led to a better context, drawing upon basic knowledge, correcting common errors, and giving feedback. The students discussed about what they were doing, or how to apply the problem-solving process.

First, a general solving strategy for each kind of multi-step question was provided indicating relevant information: equations, stoichiometric transformations, and conceptual-algorithmic components. The appropriate steps were proposed for solving as routine exercises (linear, forward-working mode) as novel problems (flexible mode). This action yielded a progressive change of cognitive process dimensions, in other words, a transition from conceptual knowledge to procedural knowledge. Secondly, blackboard and slides supported the teaching of selected multi-step examples. Different reasoning model (MBR, CBR or RBR) were used. The selection of the solving strategy drastically influenced on the future approach selected by students, because most of them directly repeated the reasoning procedure that the instructor shows in the classroom. Thirdly, the solving procedure was applied inducing the participation. The students collaborated sharing conceptual understanding, analyzing partial results, and discussing alternative strategies. The correct handling of chemical formulae, variable dimensions, and units was particularly studied. Also, intermediate results were tested to see whether any progress toward an answer was achieved. It allowed focusing on the differences between successful and unsuccessful solutions. In conclusion, a discussion scenario with active contribution of students was induced in the classroom and different reasoning models were exposed to increase the successful transfer of question solving skills (conceptual and algorithmic, LOCS and HOCS).

3.2.2 Off-class activities

Activities outside of classroom have taken on special importance in the new context of undergraduate education. Learning outcome, student satisfaction, and used time depends on both the type of activity and the format (paper documents or computer assisted). So, the use of computer provided best results for open-questions or activities of information seeking, but paper-documents were more useful for problem solving. Then, a design of instructional strategies, mainly supported by paper documents, was elaborated for the off-class learning.

End-of-chapter questions and problems for selected general chemistry textbooks is a common strategy outside of classroom (Dávila & Talanquer, 2010). Recently, our educational research group has elaborated a specific textbook for learning about multi-step problems and opened-questions, containing examples of applied solving strategies, illustrating different approaches and difficulty grades. Also, some notes are included for understanding conceptual terms involved in the problem and emphasizing the algorithm contribution. This collection of questions allowed from self-learning (individual student) to collaborative learning (self-initiated study groups).

3.2.3 Off-class group activities

Induced tasks and collaborative activities were performed outside of classroom. In the first action, students were engaged in pairs into some out-class activities for solving of practice questions. Two peers working together forced them to maintain some agreement and to reach eventually a shared solution. Students controlled their own learning process and participated in the learning process of other students (peer-learning). In the second option, small study groups were formed without participation of instructors for studying purposes. The group size, group roles, activities, resources, and temporal distribution were self-regulated. The students had to think how to resolve the problem by active learning techniques and they were all are co-learners.

In absence of instructors, the potential relationships between modes of reasoning and levels of cognitive processing can change. For instance, solving strategies were strongly dependent on students' prior knowledge (experience of what it was important for success). This fact affected both their comprehension of core chemistry concepts and the development of mental models to make predictions and build explanations related to the selection of solving strategy. Christian and Talanquer (2012) identified dominant modes of reasoning expressed by college chemistry students while working in self-initiated study groups. The group talk was largely focused on issues invoking rule-based reasoning. Also, there were some discussions about chemical reactions heavily relied on case-based reasoning, but model-based reasoning was minimally applied.

3.2.4 Group tutorials and specific seminars

Two kind of small group activities were developed controlled by instructor. The first action was based on classical tutorials where a group of students with similar difficulties participated in an adapted teaching-learning session. These activities were performed in a small room or the office of instructor. The second action was the development of specific seminars designed with the aim of discussing about the best procedure to solve, in planned sessions. The number of students in these classes is lower than 25 and organized in small groups (2-4 students). In previous courses, the teachers had an important role controlling the discussion dynamics, helping them in the group reasoning, and finally, solving the question. This adaptation of problem-based learning has been well accepted by most of the students enrolled in this subject from course 2002-2003 (Noguera, Herrero, Atienza & Tortajada-Genaro, 2008). However, some students had a passive attitude waiting until the final solving.

The innovation approach proposed in this study was based on an increase of collaboration between students. The discussion and the application of algorithm to reach by consensus were directed by students. They expressed more freely their reasoning (MBR, CBR, and RBR) and the capacity to implement their knowledge for solving the question from the understanding statement until the achievement of the final result. The teacher just participated for emphasizing theoretical concepts or practical skills related with the problem (conceptual or algorithm) or for the detection of misconceptions. These sessions were more educational than informative.

3.3 Impact of the actions

Learning achievements were analyzed by comparing those obtained by the participants (higher contribution of high-level collaborative activities) and by the rest of students enrolled in the subject. First, the learning of the skills related to solve problems was observed during seminars. On average, the number and the complexity of questions to the teacher as well as the time needed to solve a problem were reduced. Second, the collected material during the course (exams, activities, seminars) was analyzed by the evaluation rubric. No significant differences were observed respect to the reasoning models performed by students during the solving of chemical questions. However, the total number of errors was reduced respect to the previous courses (up to 10 %). The higher decrease corresponded to the chemical errors, indicating that a deeper knowledge was induced. Third, the marks for multi-step questions of the exams were analyzed. On average, participants in this study had slightly higher grade point averages (a mean increment about 10%) than the average for all of the students in the course.

From the teacher's point of view, the proposed change involved similar efforts for preparing materials. The innovation was centered in the teaching style, more inquisitory lectures and more activities controlled by the students (collaborative activities). Hence, the general conclusion was that the teaching adaptation to high-level collaborative actions between students showed positive consequences in two year-study. However, more data are required to assure the statistical significance of these results, discriminating the effect of teaching-learning action and the inter-variation of student groups. For instance, the improvement in student achievement was significantly dependent on the previous chemical and mathematics level and motivation. Additionally, the previous learning experiences conditioned the proposed teaching action. It was difficult to change the reasoning strategy, because those students were used to solve questions following a predetermined mode (effective or not).

3.4 Student perception

After a short explanation of the educational research concepts, the student opinion survey based on a questionnaire was performed, including some Likert-scale questions and an open-ended question. The main results are shown Figure 2. In the first question, the students were auto-classified on cognitive development spectrum solving the multi-step problems. They had to decide from a learner focused on the mathematical solving to a learner focused on the conceptual aspects. An important part of asked students (44%) considered themselves as high or medium algorithmic learners. Also, the percentage of high or medium conceptual learners was relevant (24%). Despite of the teaching efforts, these results confirmed the importance of a shift of chemistry instruction to a more conceptual orientation in order to balance the learning of chemistry, but teachers cannot forget that some students show deficiencies in algorithmic components of this subject. In the following questions, the incidence of different activities or resources available in the teaching-learning scenario was evaluated. According to the opinion of participants, low-collaborative activities helped them to learning solving strategies. The survey data surprisingly indicated than inquisitory lectures (14.5%) had a comparative contribution than expository lectures (14.4%), even with an increment of student participation and an induced peer-learning. On the other hand, the textbook specifically designed for self-learning and collaborative actions (13.8%) showed a higher impact than other textbooks or internet resources (4.4% and 7.1%, respectively). With respect to high-collaborative activities, induced tasks (8.4%) were apparently less efficient than collaborative actions carried out by self-initiated study groups (15.2%). Nevertheless, innovative specific seminars (14.4%) were better accepted by students than classical group tutorials (7.9%). In the open-ended question, the students positively evaluated the methodology used for problem solving and they also proposed changes, for example that the teacher should provide more solved problems.

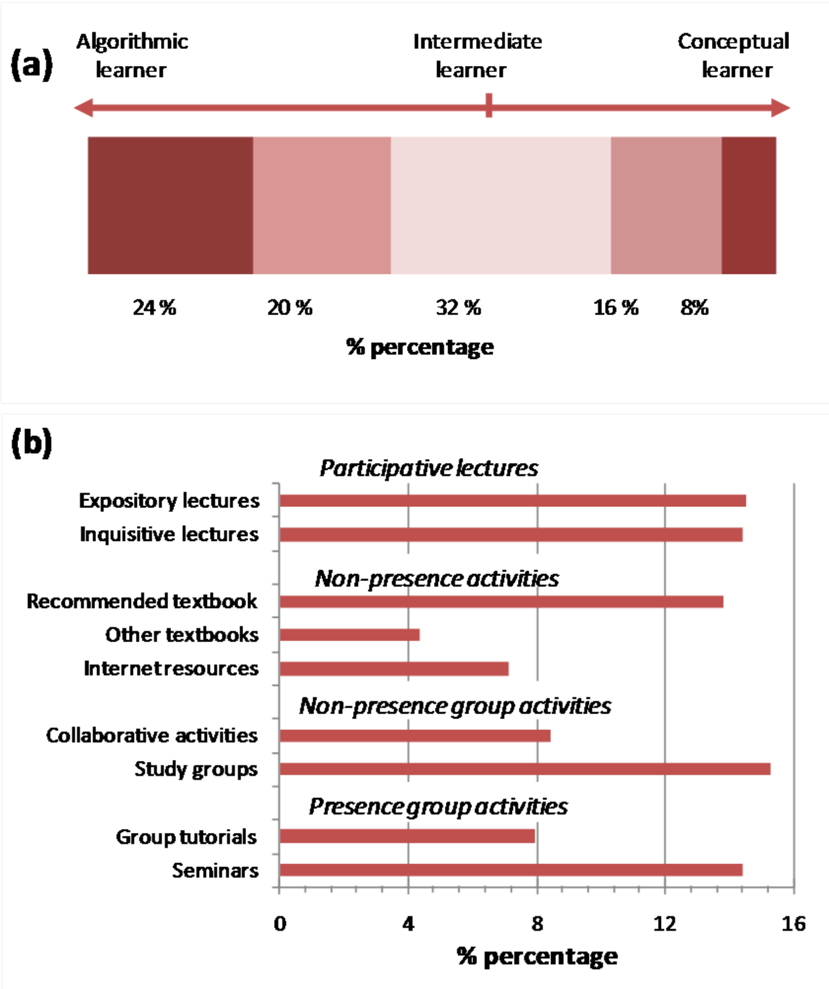

Figure 2. Survey results: (a) Auto-classification of students according their cognitive development. (b) Relative contribution of teaching-learning activities on learning efficiency for problem solving

4 CONCLUSIONS

Chemistry teachers utilize different tools to build and communicate the knowledge and the skills required for engineering students. Multi-step questions are an excellent platform for showing how chemical concepts are useful for solving scientific-technical problems. Also, these questions induce more robust reasoning models and, consequently, are able to be applied in novel situations. For that, the algorithmic-type learning is a common practice. Unfortunately, such memorization techniques promote an approach that hinders meaningful learning and true understanding. The results of this paper have showed that collaborative activities are a positive action to support deep knowledge and high-level thinking skills. A modification of instruction has been analyzed indicating a mode to do it, inside and outside of classroom, and the expected outcomes and difficulties. It is worth mentioning that the proposed changes involve a small adaptation of common lectures, seminars, and resources. However, the active participation of students leads to a more effective teaching and peer-learning, correcting misconceptions, and reinforcing theoretical concepts. Collaborative activities make easy the problem-solving process because students discuss about the relevant information from the problem statement, the analysis of chemical concepts, and the selection of the best algorithm toward the answer. These steps are particularly important in determining the success or failure to obtain the correct numerical answer, including its units. Data collected by observation and survey (questionnaire) indicated that the applied methodology was satisfactorily accepted by students.

REFERENCES

Bodner, G.M. (2003). Problem solving: the difference between what we do and what we tell students to do. *University Chemistry Education*, 7(2), 37-45.

Christian, K., & Talanquer, V. (2012). Modes of reasoning in self-initiated study groups in chemistry. *Chemistry Education Research and Practice*, 13, 286-295. http://dx.doi.org/10.1039/c2rp20010d

Dávila, K., & Talanquer, V. (2010). Classifying end-of-chapter questions and problems for selected general chemistry textbooks used in the United States. *Journal of Chemical Education*, 87(1), 97-101. http://dx.doi.org/10.1021/ed8000232

Dori, Y.J., & Hameiri, M. (2003). Multidimensional analysis system for quantitative chemistry problems: symbol, macro, micro, and process aspects. *Journal of Research in Science Teaching*, 40, 278-302. http://dx.doi.org/10.1002/tea.10077

Herrero, M.A., Atienza, M.J., Noguera, P., & Tortajada-Genaro, L.A. (2008). *La Química en problemas. Un enfoque práctico*. Valencia: UPV.

Kovac, J.D. (1999). Student active learning methods in General Chemistry. *Journal of Chemical Education*, 76(1), 120-124.

Kraft, A., Strickland, A.M., & Bhattacharyya, G. (2010). Reasonable reasoning: Multi-variate problem-solving in organic chemistry. *Chemistry Education Research and Practice*, 11, 281-292. http://dx.doi.org/10.1039/c0rp90003f

Lee, J. (2003). Malpractices in chemical calculations. *University Chemistry Education*, 7(1), 27-32.

Noguera, P., Herrero, M.A., Atienza, M.J., & Tortajada-Genaro, L.A. (2008). *General chemistry for engineers: a student´s point of view*. Proceedings of INTED2008 Conference, March 3rd-5th, 392.

Smith, K.C., Nakhleh, M.B., & Bretz, S.L. (2010). An expanded framework for analyzing general chemistry exams. *Chemistry Education Research and Practice*, 11, 147-153. http://dx.doi.org/10.1039/c005463c

Taber, K.S., & Bricheno, P.A. (2009). Coordinating procedural and conceptual knowledge to make sense of word equations: Understanding the complexity of a 'simple' completion task at the learner's resolution. *International Journal of Science Education*, 31(15), 2021-2055. http://dx.doi.org/10.1080/09500690802326243

Taber, K.S., & García-Franco, A. (2010). Learning processes in chemistry: Drawing upon cognitive resources to learn about the particulate structure of matter. *Journal of the Learning Sciences*, 19(1), 99-142. http://dx.doi.org/10.1080/10508400903452868

Talanquer, V. (2006). Common sense chemistry: A model for understanding students' alternative conceptions. *Journal of Chemical Education*, 83(5), 811-816. http://dx.doi.org/10.1021/ed083p811

Zoller, U., Dori, Y.J., & Lubezky, A. (2002). Algorithmic, LOCS and HOCS (chemistry) exam questions: performance and attitudes of college students. *International Journal of Science Education*, 24(2), 185-203. http://dx.doi.org/10.1080/09500690110049060

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