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ASSESSMENT OF ACHIEVEMENT IN PROBLEM-SOLVING SKILLS IN A GENERAL CHEMISTRY COURSE

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Abstract

This article reports the development and validation study of tests to assess achievements at three levels of knowledge structure, following the model proposed by Sugrue to measure problem-solving skills. The literature has reported this proposal as a model consistent with the theoretical constructs underlying problem-based learning (PBL) methodology. The tests were constructed for a General Chemistry course in a curriculum of engineering, which implements PBL methodology at a Peruvian university. The content validation of the tests was performed, as well as a pilot implementation with Peruvian students of first year engineering. The results obtained in omissions percentage, difficulty degree, items response pattern and the point biserial coefficient (rpb), let us to conclude that these are appropriate tools for assessing these skills, mainly for the purpose of contributing to process facilitation as well as to future research in this line.

Keywords – Problem-solving skills, Academic achievement, Problem-based learning, Higher education.

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1 INTRODUCTION

Despite the variety of approaches to problem-based learning, in terms of its definition and different modalities of implementation (Dochy, Segers, Van den Bossche & Gijbels, 2003; De Graaff & Kolmos, 2003), there is no doubt that there is a consensus to point out that from the cognitive dimension, one of the main objectives in this educational proposal is the development of problem solving skills both for the acquisition of knowledge, as for its application (Hmelo-Silver, 2004). Although there is a large volume of research on PBL, there is no consensus on what achievements or what measurement methods should be used to evaluate their effects, and this situation leads to the need to identify relevant theoretical constructs underlying PBL features and main goals in the learning context (Newman, 2003). The meta-analysis performed by Gijbels , Dochy , Van den Bossche and Segers (2005), used Sugrue's model (1994, 1995) as a frame of reference to study the PBL effects when the assessment of its main goals focuses on the understanding of concepts, principles that link concepts, and the linking of concepts and principles to conditions and procedures for application. For the authors, the great advantage of Sugrue model is that it is translated into specifications for the assessment of the main cognitive components of problem solving: knowledge structure, metacognitive functions, and motivation.

This study follows the line of work of Gijbels et al. (2005), to develop instruments with the purpose to monitor student achievement in three levels of knowledge structure using Sugrue model, in a General Chemistry course where a hybrid PBL approach was implemented.

1.1 PBL theoretical framework

PBL methodology is part of an educational vision that promotes an open, critical, and reflective learning with a holistic approach to knowledge that recognizes their complex and changing nature, and involves a community of people who interact collaboratively to make decisions regarding different problem situations they must face. PBL, in this sense, is the medium to set the conditions to promote active, contextualized, integrated and comprehension oriented learning, providing opportunities to reflect on the educational experience and to practice the application of learning (Margetson, 1997; Engel, 1997). Therefore, it is clear that the learning goals go far beyond the mere acquisition of disciplinary content.

The scenario or problem that initiates the learning process fulfills several functions during the process: to organize the content and knowledge; provide the context of the learning environment, stimulate higher order thinking and reflection, as well as promoting and maintaining motivation for learning. Hung (2006) proposes an interesting model that clearly illustrates the different components of the scenario or problem design, and can be a reference to identify the main issues involved in PBL learning goals.

The core components of the model: content, context and connection are mainly related to the ownership and adequacy of content knowledge, and their contextualization and integration. The content, as a central component, validates proper alignment between the problem scope and the curricular contents (expected learning) in breadth and depth. The context ensures that the situation presented is authentic (real or realistic), relevant to the professional area in which the student is formed, their personal interests or his life as a member of society. The connection component enables students to integrate knowledge and interconnect the concepts in such a way of establishing a conceptual network of the subject.

Processing components: research, reasoning and reflection facilitate conscious and meaningful involvement of students in their learning process. They are the dynamic elements of the model, thus, research enables the core components, promotes the development of skills for the search and processing of information, facilitates conceptual connections for student learning and supports the processes of reasoning and reflection. The reasoning component promotes the development of skills of higher order thinking, actives core components also facilitates student conceptual connections and supports the processes of research and reflection. The latter component acts as a guiding element for metacognition, facilitates reflection process to synthesize and integrate the knowledge learned, promotes in students the habit to develop and use their skills to self-directed learning and lifelong learning.

There is an additional important element to consider: PBL process is developed on the basis of efficient teamwork dynamics. The influence of interpersonal relationships and communication with others about learning is recognized in both learner-centered psychological principles proposed by APA (1997), and the constructivist view of teaching and learning (Coll, 2001). Working collaboratively with peers favors the activation of prior knowledge, provides opportunities for exchange of ideas contributing to the restructuring of patterns of knowledge, stimulates epistemic curiosity, attitude and motivation for learning (Schmidt, 1983).

According to discussed so far, PBL methodology helps students to construct an extensive and flexible knowledge base; develop effective problem-solving skills; develop self-directed, lifelong learning skills; become effective collaborators; and become intrinsically motivated to learn (Hmelo-Silver, 2004).

The adoption of PBL involves substantial changes in various aspects related to institution, teachers and students, which will ultimately determine the achievement of the fundamental goals of this educational proposal. This transition is not a simple process and therefore, it has emerged a variety of approaches to the methodology ranging from adoption in isolated courses belonging to a traditional curriculum, until joining a radical curricular transformation (Dochy et al., 2003). The diversity of approaches has hampered the interpretation of results of research on their effectiveness (Camp, 1996), which is why from the late nineties, several studies have recognized the need to consider the characteristics of the specific context in where the PBL implementation is performed, in order to have more and better information for evaluating the achievements of the methodology and the factors that may affect them (Dochy et al., 2003; Gijbels et al., 2005; Neville, 1999; Newman, 2003).

1.2 PBL approach implemented in the study

In Latin America Engineering Programs the more frequent experiences correspond to PBL approaches, mainly hybrid models that incorporate different kind of variations of the original model, implemented in one single course. In the case of the General Chemistry course were this study was performed, each unit was organized as shown in Figure 1.

• ***Presentation of the PBL scenario of the unit*** • ***First Brainstorm***	
Autonomous work group	***Learning activities carried out under the guidance of Professor***
• *Group brainstorming and planning strategies to address the problem*	• Groups work in collaborative activities, designed by the professor and related to the learning objectives of the unit
• *Research and group discussion*	• Mediation of professor performs both in cognitive aspects, as well as in the group performance monitoring.
• Review and adjustment of the strategy	• Professor adapts the mediation, according to the progress of the students and stimulates the debate of ideas and decision-making.
• **End of the unit: groups present their proposals for a solution to the problem**	

Figure 1. Hybrid PBL approach implemented in the General Chemistry course

The assessment of each unit considers the proposal of solution for the PBL scenario, collaborative learning activities performed with mediation of the Professor, the electronic portfolio and two individual tests: one of multiple options to evaluate achievements in the three levels of the structure of knowledge according to the model of Sugrue, and other of open response relating to the contents of the unit.

1.3 Problem solving skills in Sugrue model

The literature on problem solving skills is characterized by displaying multiple theoretical frameworks from cognitive science or information processing. However, comprehensive models of its components have been proposed based on the review and compilation of results from several research lines. Sugrue examined common issues of some of these models, in order to identify a set of cognitive components that could be measured to estimate the extent to which a student can solve problems within a domain, such as science, as well as provide a basis for selecting a subset of variables to be submitted for evaluation.

The three cognitive components to be assessed in problem solving following Sugrue model are:

- Cognitive Functions, component that supports flexible adaptation of self-knowledge to meet the demands of a new problem. It is related to the so-called metacognitive functions, or processes of higher order thinking,
- Beliefs, component that aims to generate a comprehensive profile of the student's ability and willingness to solve problems in a particular domain, through variables: self-efficacy , perception of task demands and perceived attractiveness of the task,
- knowledge structure, this component consists of three levels that, in a perfect performance, show a high degree of connectivity, integration and consistency.

Sugrue suggests that the ability to solve problems in a particular domain results from the complex interaction of the structure of knowledge, metacognitive functions and motivation. The differences observed during the process, from the interpretation of the problem to the persistence in trying to solve it, can be attributed to variations in these three aspects of cognitive constructs. For each of the three categories of cognitive components, Sugrue describes a limited set of variables that should be targeted by assessment under two criteria: they were shown to be critical by research or open to instructional intervention. In this study, interest has focused on developing tools to assess achievements in the component knowledge structure, so this theme is developed in more detail in the next section.

1.4 Knowledge structure assessment

This component of Sugrue model considers three levels:

- First level: Concepts. A concept is a category of objects, events, people, symbols and ideas that share common attributes and properties, and are identified by the same name. The evaluation of the understanding of a concept implies: selecting examples of the concept (in a multiple choice format), or generating of examples of the concept (in an open-ended format), or explanation of why examples reflect concept attributes (in a hands-on format).
- Second level: Principles. A principle is defined as a rule, law, formula or statement that characterizes the relationship (often causal) between two or more concepts. The evaluation of the understanding of principles involves: selecting best predictions or best explanation (in a multiple choice format), or generating predictions or solutions (in an open-ended format), or giving an explanation of an event or result (in a hands-on format).
- Third level: Linking the concepts and principles to conditions and procedures for application. To facilitate the resolution of the problem, the concepts and principles should be linked to the conditions and procedures that facilitate their use in new situations. A procedure is a set of steps that can be done to achieve a goal. The conditions are aspects of the context that indicate the existence of an instance of a concept, or to indicate that a principle is operating or can be applied, or that a particular procedure is appropriate. Subjects with good performance in problem solving should be able to recognize situations where procedures can be performed to identify or generate instances of a concept and should be able to carry out these procedures exactly. Overall, they should be able to assemble a procedure based on a principle to construct a desired achievement in a new situation. The evaluation of this level involves: selecting correct procedure for identifying instances of a concept, or selecting most appropriate procedure to change the state of one concept by manipulating other (in a multiple-choice format); or generating a procedure for identifying instances of a concept, or generating a procedure to change the state of one concept by manipulating other (in a multiple-choice format); or performing procedures to identify instances of a concept, or performing a procedure to change the state of one concept by manipulating other (in a hands-on format).

The diagnostic evaluation of problem solving skills should allow the identification of students who understand the concepts but not the principle that binds them, students who understand the principles and concepts but have no knowledge of the procedures for applying them, and students who are able to perform procedures correctly but do not know when it is appropriate their application.

The findings of Gijbels et al. (2005) showed no significant differences in the first level, corresponding to the understanding of concepts, comparing the achievements reported in PBL implementations with conventional teaching methodology. However, in the second level, corresponding to the understanding of principles linking concepts, PBL showed significant superiority. There were not enough studies on the third level of the model, for this reason, previous research aimed to develop tests to assess achievements in the third level that were applied to freshmen engineering courses, in the context of General Chemistry and General Physics courses (Morales 2011a, 2011b).

The aim of the present study is to develop and validate instruments that can be used for the assessment of cognitive achievement in the three levels of knowledge structure, based on a model that is consistent with the learning environment promoted by methodologies such as PBL.

2 METHODOLOGY

2.1 Instruments construction

The first task in the construction of the tests was to identify the concepts, principles and the conditions and procedures that were to be evaluated in the main thematic units of General Chemistry 2 course. To do this, it was conducted a content analysis of topics and issues in the curriculum, to detail the domain and sub-domain of interest and decide the level of assessment. Then the items were written taken as reference Sugrue model for evaluating three levels of Knowledge Structure: concepts, principles and link the concepts and principles to conditions and procedures for application, resulting in the construction of three tests, one for each topic: Thermodynamics, Kinetics and Chemical Equilibrium. The format used for all the tests was multiple choices.

The items were formulated in such a way that for the first level, the student should identify examples of the concept. At the second level, the student should select the best explanation of a particular event and in the third level, the student must select the correct procedure to identify concepts in a given situation, or select the most appropriate procedure to change a concept status manipulating another concept.

Some examples:

- First level:

  The soldiers often bring prepared food placed in a closed plastic bag or aluminium foil, which can be heated by immersing it in boiling water or by placing it on the hot engine of a vehicle. Another possibility is to use the "flameless heaters," which utilize a reaction between magnesium metal and water, which is very exothermic.

  From the text above:

  Identify a thermodynamic system and indicate its type (open, closed, isolated), justifying your answer.

- Second level:

  It is suspected that the decomposition of a biological substance follows a first order kinetics. To confirm this, the concentration of the substance was measured at different times. What must we do with this data?

  - We must determine the concentration which decomposed, as the difference between the initial concentration and the remaining concentration at each time. If the graph of the obtained values versus time is a straight line, then it is a first order reaction.
  - We must calculate the inverse of concentration at each time. If the graph of the obtained values versus time is a straight line, then it is a first order reaction.
  - We must determine the log of the inverse of concentration at each time. If the graph of the obtained values versus time is a straight line, then it is a first order reaction.
  - We must determine the log of the concentration at each time. If the graph of the obtained values versus time is a straight line, then it is a first order reaction.

- Third level:

  We want to increase the acidity of a solution containing 0.1 M acetic acid (Ka = 1.8×10^{-5}). In the laboratory we find the following aqueous solutions: hydrocyanic acid 0.1 M (Ka = 6.2×10^{-10}) and nitrous acid 0.1 M (Ka = 4.0×10^{-4}). Which of the following alternatives will achieve the goal?

  - Add a volume of the nitrous acid solution, which is a stronger acid and provide greater amount of H+ ions to the acetic acid solution, increasing its acidity.
  - Add a volume of the hydrocyanic acid solution, which is a stronger acid and provide greater amount of H+ ions to the acetic acid solution, increasing its acidity.
  - Increase the volume of the acetic acid solution by adding water, so acid ionization will increase and therefore the acidity.

2.2 Content validation

This is the most important stage in the validation process, as it shows the logical relationship between test items and content and skills assessed. For this case, five Chemistry professors from Pontifical Catholic University of Peru (PUCP) were invited to assume the role of judges in assessing the degree of coherence between the concepts and principles to be assessed with each item and the item statement. Also, they were asked to assess the degree of consistency between the learning objectives associated with each item and the item statement.

On the basis of the judges' evaluation and their comments and suggestions, adjustments were made to the items in each test, to proceed with their pilot application and a reassessment by three Chemistry professors from PUCP who participated as judges.

2.3 Pilot application

The tests were applied with students of General Chemistry 2 course (PUCP) following a hybrid PBL approach in different semesters between 2010 and 2011. The ages of the students involved ranged between 17 and 20 years, with the highest percentage at the age of 17 years (43.2%). Table 1 reports further information about participants in the pilot implementation of each test.

Test	***N° participants (N)***	***Gender (%)***	
		Male	***Female***
Thermodynamics	*328*	*73,1*	*26,9*
Kinetics	*313*	*69,0*	*31,0*
Chemical Equilibrium	*283*	*70,5*	*29,5*

Table 1. Information about participants in the pilot implementation of each test

The test application was always made at the end of the corresponding thematic unity. The maximum duration of application was 50 min. With the tests responses, it was performed the analysis of items for each of the three tests. For this purpose it was determined:

- the percentage of omissions, corresponding to reactive responses that have been left in blank,
- the difficulty degree, which is a measure of the number of subjects who responded correctly to the reagent;
- biserial point coefficient (rpb), which is a special case of Pearson correlation for determining the correlation between the reactant and the total score and constitutes an internal discrimination index.

3 RESULTS

3.1 Instruments construction

Table 2 summarizes the final structure of each test.

Test	***N° First level items***	***N° Second level items***	***N° Third level items***
Thermodynamics	*2*	*1*	*3*
Kinetics	*2*	*2*	*2*
Chemical Equilibrium	*1*	*1*	*3*

Table 2. Final structure of each test

3.2 Content validation

Table 3 summarizes the results of the second judges' evaluation of the built tests. The evaluation by the second group of judges was satisfactory, qualifying the degree of consistency between the questions and the learning objectives, concepts and principles associated, as good or very good.

Test	*Degree of consistency (%) between test items and:*			
	Learning objectives		*Concepts and principles*	
	Very good	*Good*	*Very good*	*Good*
Thermodynamics	*78*	*22*	*83*	*17*
Kinetics	*83*	*17*	*89*	*11*
Chemical Equilibrium	*80*	*20*	*87*	*13*

Table 3. Summary of second judges' evaluation of the built tests

3.3 Pilot application

Table 4 summarizes the results of analysis of items for each of the three tests. The percentage of omissions is not included, because in all cases the participating students answered the total of questions.

Test	*Level*	*Item*	*Difficulty degree (%)*	*Proportion of errors*	*rpb*
Thermodynamics	*1*	*1*	*56,4*	*0,436*	*0,433*
	1	*2*	*65,5*	*0,345*	*0,475*
	2	*3*	*54,6*	*0,454*	*0,585*
	3	*4*	*41,5*	*0,585*	*0,478*
	3	*5*	*80,8*	*0,192*	*0,418*
	3	*6*	*43,6*	*0,564*	*0,466*
Kinetics	*1*	*1*	*66,8*	*0,332*	*0,488*
	1	*2*	*83,7*	*0,163*	*0,476*
	2	*3*	*78,9*	*0,211*	*0,461*
	2	*4*	*62,9*	*0,371*	*0,484*
	3	*5*	*64,2*	*0,358*	*0,511*
	3	*6*	*57,4*	*0,426*	*0,469*
Chemical Equilibrium	*1*	*1*	*71*	*0,29*	*0,510*
	2	*2*	*35,3*	*0,647*	*0,519*
	3	*3*	*56,2*	*0,438*	*0,586*
	3	*4*	*32,2*	*0,678*	*0,463*
	3	*5*	*61,5*	*0,385*	*0,476*

Table 4. Summary of the results of analysis of items for each test

The average of degree of difficulty for the Thermodynamics test was 57.07%; for Kinetics test the value obtained was 68.98% and for Chemical Equilibrium test was 51.24%. According to this, the second test can be classified as moderately difficult, while the first and the third tests would qualify as medium difficulty. The variability of the values obtained for the items in each test was adequate, showing that it contained questions of different levels of difficulty for students. Biserial point coefficient (rpb) is located in the range 0.418 to 0.586 for all items of the tests, so it is an indication that the reagents of each test discriminate between subjects achieving high score on the test and those with low scores.

Figure 2 shows, as an example, a comparison of the results in the evaluation of achievements in the three levels of knowledge structure of three students, using Thermodynamics test.

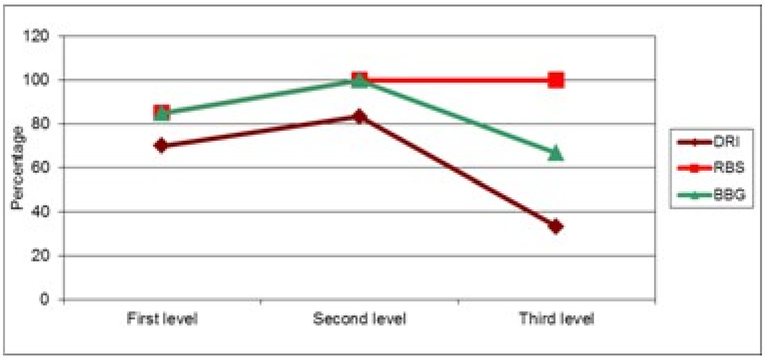

Figure 2. Evaluation results on the three levels of knowledge structure of three students in a General Chemistry course

It can be seen that the student RBS had very satisfactory results according to the learning goals of PBL methodology. The student BBG had very good levels of achievement in concepts and principles, but must improve his skills in the third level. Something similar happens with the student DRI, although his results are lower, especially in the third level, so he may require special attention.

The overall results in the application of these instruments with a group of students allow the professor to get information about achievement in terms of expectations in line with PBL approach. According to it, the facilitator can have evidence to reformulate the problems, learning activities or his facilitation.

For example, Figure 3 shows that the results in Chemical Equilibrium test were lowest in the group of students assessed, so it would be necessary to analyze the reasons of this situation for planning corrective action.

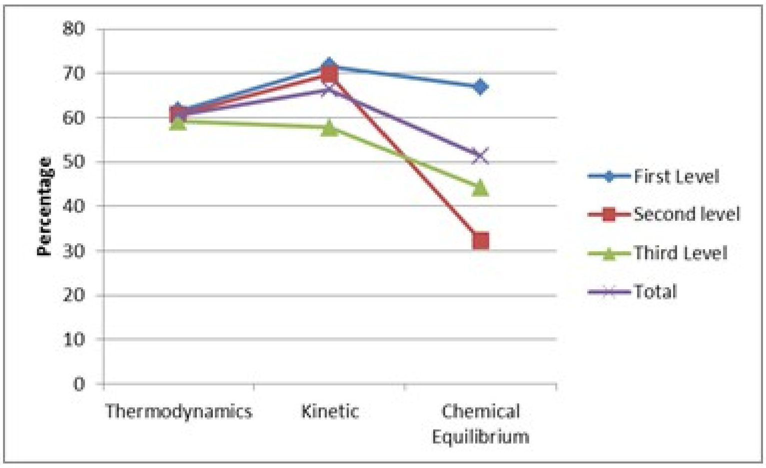

Figure 3. Global results on the three levels of knowledge structure for each test

4 CONCLUSIONS

The results obtained in the validation of the built instruments are highly satisfactory, since, first, ensure a high degree of consistency between the learning objectives, the content assessed and the items in each test. The theoretical foundations of the model have been applied rigorously and are relevant to the learning contexts promoted by PBL methodology.

In relation to the analysis of items in each of the tests, it can be seen that a very good range is reached in the coefficient of internal discrimination, which is very valuable for future studies using these instruments. It can be corroborated also a trend toward higher levels of difficulty in items of the third level of knowledge structure. It is noteworthy that in PBL implementations are expected to have significant achievements especially at this level.

As noted in earlier sections of this report, there is a major difficulty for the evaluation of achievements in the implementation of PBL methodology, which is related to the construction and application of appropriate tools for measurement. Sugrue's model provides a suitable and understandable framework that supports the criteria for the construction of test to assess problem-solving skills, such as demonstrated in our investigations. In this study, the model helped the development of three instruments to assess achievements in three basic thematic units of General Chemistry. According to the results of the validation, the tests built have robust features for their use as tools to monitor student achievement in three levels of knowledge structure using Sugrue model, as well as in future research to explore achievements in the use of PBL methodology in contexts similar to that reported here.

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