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Reptes de futur en l'ensenyament superior: Docència i investigació per a aconseguir l'excel·lència acadèmica

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A "Know-How vs. Know-What" Approach in the Teaching-Learning of Competences in Physical Chemistry

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ABSTRACT

The methodological approach a teacher uses in the competence teaching-learning process determines the way students learn. Knowledge can be acquired from a series of perspectives, mainly: "know-what" (concept), where facts and descriptions of (natural or social) phenomena are pursued; "know-how" (procedure), where methods and procedures for their application are described; and "know-why" (competence), where general principles and laws that explain both the facts and their applications are sought. As all the three cases are interconnected, the boundaries between them are not fully clear and their application uses shared elements. In any case, the depth of student's acquired competences will be directly affected by the teaching-learning perspective, traditionally aiming to a "know-why" approach for full competence acquisition. In this work, we discuss a suitable teaching-learning methodology for evaluating whether a "know-how", "know-what" or combined approach seems better for enhancing competence learning in students. We exemplify the method using a selection of formative activities from the Physical Chemistry area in the Grades of Chemistry and Chemical Engineering.

Keywords: Know-What; Know-How; Know-Why; Physical Chemistry; Competences.

1. INTRODUCTION

The European Higher Education Area (EHEA) has triggered a substantial change in the teaching-learning process, as the focus changes from the knowledge acquisition (concepts and skills) to its mobilization in a particular context with appropriate cognitive strategies (competences; Barnett, 2001). This paradigm shift is particularly patent in the European credit system (ECTS) that explicitly takes into account the number of hours students devote to the learning process, which puts into context the application of knowledge rather than its mere accumulation, and reallocates the role of teachers as true mentors instead of mere lecturers (Izquierdo, 2005).

Regardless of the teaching-learning paradigm, the final learning outcome is "knowledge" that can be categorized into three types (Figure 1; Garud, 1997):

1. Know-what: related with concepts, facts and descriptions. Knowledge is created through a "learning-by-using" approach (repetition or identification of concepts).
2. Know-how: related with skills, procedures and methods. Knowledge is created through "learning-by-doing" (practical, applied or hands-on experience).
3. Know-why: related with competences, theories and experimentation. Knowledge is created through "learning-by-studying" (understanding of phenomena principle and applying them to new contexts).

"Know-what" remains on the surface of knowledge, while "know-why" delves into its roots for its application on changing environments. Both "know-how" and "know-why" require longer acquisition times for full mastery, as opposed to "know-what". In addition, the application of "know-how" comes after learning and obtainment of "know-why" and "know-what". From the EHEA perspective, universities should promote a "know-why" approach so that competences could be fully developed on students. In any case, all three components do not operate in a separate fashion but synergistically, i.e. in parallel (synchronized) depending on the requirements for fulfilling the task at hand.

In the context of Chemistry, its learning can be conventionally done through a two-fold approach (Chin and Brown, 2000): surface or deep learning. In the first case, students tend to explain concepts through the reformulation of questions, with a description that lacks a thorough understanding of chemical principles; on the contrary, a deep learning engages students in more elaborate reasoning with chemical principles, looking for causal relationships between phenomena. Physical Chemistry is particularly multidisciplinary in

nature, and as such its structure deals with many distinct fields, such as classical and statistical thermodynamics, chemical kinetics, quantum mechanics or spectroscopy, which provide the physical foundations for many other chemistry areas (Mahan, 1970). Its nature is very appropriate to make a deep analysis in terms of the type of knowledge involved in its teaching-learning process.

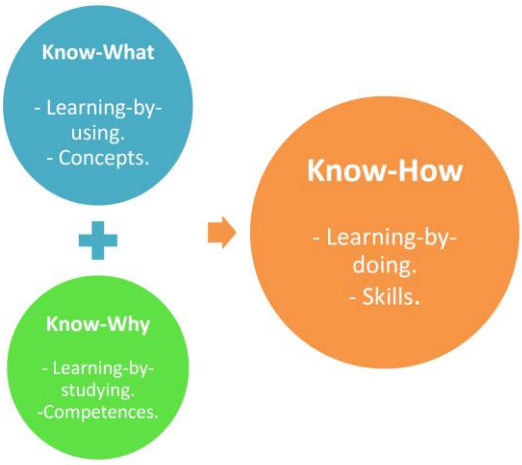

Figure 1. Knowledge components with their elements and relationship. Adapted from Garud, 1997.

A teaching-learning (instructional) model that provides a multi-faceted knowledge approach with a deep learning of competences should (Figure 2; Wink, 2010): (i) engage students in scientific questioning, (ii) provide students with opportunities to explore and create their own explanations, (iii) provide scientific explanations and connect them with students prior explanations, and (iv) create opportunities for students to extend, apply and evaluate what they have learned. These features resemble those of the scientific method and stem from a constructivist knowledge perspective. Some models using these features include the Process Oriented Guided Inquiry Learning (POGIL; Farrell, Moog and Spencer, 1999) or the problem-based learning (PBL) with true "problems for learning" (Izquierdo, 2005). In this work, we propose a problem-based approach for evaluating which type of knowledge ("know-how", "know-what" or "know-why") is best for full competence acquisition in the different subjects of the Physical Chemistry area in the Grades of Chemistry and Chemical Engineering. An objective level classification of problems is proposed, as well as a way to

identify which type of problem is most suitable for obtaining optimum learning outcomes. Finally, a multi course plan is proposed for assessing the suitability of the exposed approach.

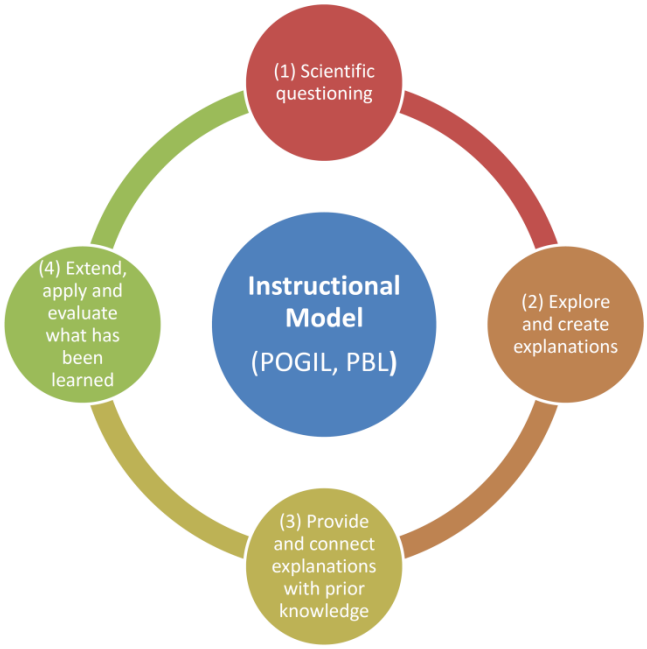

Figure 2. Components and examples of instructional models for full competence mastering. POGIL: Process Oriented Guided Inquire Learning, PBL: Problem-Based Learning. Adapted from Wink, 2010.

2. DEVELOPMENT OF THE RAISED QUESTION

The aims of this contribution are: (i) to study the different teaching-learning processes that are involved using a "know-what" or "know-how" approaches in Physical Chemistry subjects of the Grades of Chemistry and Chemical Engineering, (ii) to propose a multi-level problem-based learning (PBL) scheme to distinguish the advantages of a "know-what" vs. a "know-how" approach in competence acquisition, and (iii) span this approach in various courses within a particular grade with explicit suggestions on how to analyze the viability of both approaches on the efficiency of the teaching-learning process for obtaining optimum learning outcomes.

Problem-based learning requires first the definition of problem. In this context, we have adopted a mixed approach, in which we define problems in a different way depending on the depth level we use. For instance, a more algorithmic type of problems (e.g. exercises) is

used in the initial PBL stages, and more heuristic and open problems (e.g. projects) are employed at higher levels. In any case, the problem resolution requires a set of common steps: to read and understand the problem, to conceive a solution plan, to execute the plan, and, finally, to verify the obtained results (Izquierdo, 2005). The PBL levels that we are envisaging are the following (Figure 3):

1. Level I ("Know-what", concepts): problems deal with one concept, are written in a known context and require one known strategy for solving them (closed solution, convergent thinking). Examples: true-false questions, multiple choice questions, and short-answer questions.
2. Level II ("Know-why", competences): problems deal with one concept and method, are written in an unknown context and require many known strategies (multiple solutions, divergent thinking). Examples: exercises and conceptual derivations.
3. Level III ("Know-how", skills): problems deal with many concepts and methods, are written in an unknown context and require many unknown strategies (open solution, creative thinking). Examples: open-ended problems and projects.

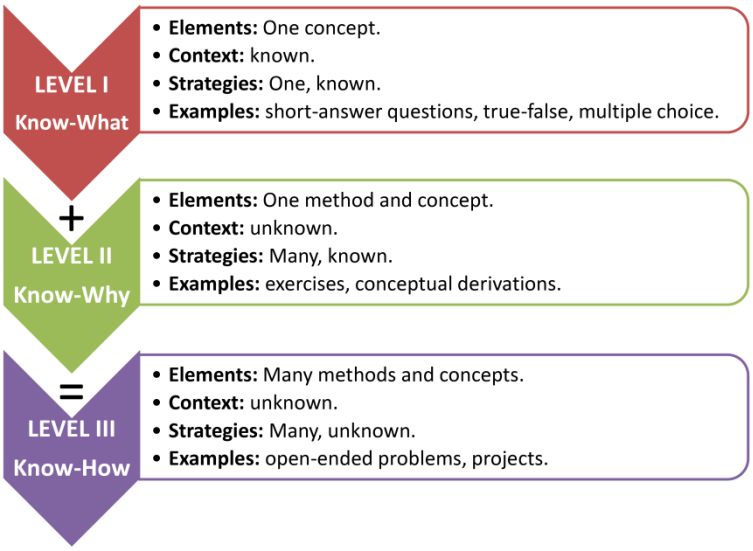

Figure 3. Multi-level approach to a problem-based learning (PBL) for full acquisition of the different knowledge components, including their features and some examples of each level.

This multi-level approach requires a suitable assessment method for obtaining significant conclusions about knowledge acquisition. A relative level of competence (from 1

to 5, being 1 the lowest level) can be used altogether with the learner portfolio as a tool for formative competence assessment (Monllor-Satoca et al., 2012). In addition, problems should be written with the proper structure (Annexes 1 and 2): "know-what" problems require a more detailed description and directives to solve them, while "know-why" problems should encourage to find limiting cases and tendencies instead of a unique solution; finally, "know-how" problems should have a minimum description that encourages students to construct the solution by themselves and using any available data source through a research-type approach.

In order to verify which knowledge approach seems more suitable for obtaining optimum learning outcomes, a stepwise teaching protocol is proposed. A class or study group could be divided in two control groups: one of them (Group 1) would follow a traditional approach starting with a "know-what" perspective, whereas the other (Group 2) would start from a "know-how" point of view. For a given content, Group 1 would make extensive use of the preferred problem level at the first instance, and once acquired, they would solve a "know-how" problem set as final project; on the contrary, Group 2 would start from a big question or problem to solve and teacher will sequentially solve the problem introducing different concepts and theories (constructivism); once the problem is solved, the group will be assessed using typical "know-what" problems. These bottom-up (Group 1) or top-down (Group 2) teaching models require the "know-why", which in the first case is sequentially taught for solving the final project but in the latter case is simultaneously introduced by the teacher. Once all learning outcomes are assessed, teacher would be able to answer this question: can a "know-what" centered learning process eventually yield a "know-how" competence?

Another important variable that could be forgotten in this approach is the students´ maturity, which increases over time and is apparently larger in the last grade courses. To study its effect, a multi-course assessment is required to elucidate the relevance of each knowledge type: in the first courses, a unique "know-what" and "know-why" can be used; subsequently, "know-how" can be introduced, until its relative weight reaches a significant presence in the formative activities (e.g. 1st course: 50% know-what, 50% know-why; 2nd course: 30% know-what, 50% know-why, 20% know-how; 3rd course: 20% know-what, 40% know-why, 40% know-how). The presence of "know-why" activities seems relevant throughout the whole grade subjects as they explicitly help develop students competences , which are required for solving unknown problems in their future professional life ("know-how").

The proposed protocol has some advantages over other traditional teaching-learning models:

- Distinguishes the different types of knowledge that have a role on competence acquisition, identifying which type has more importance.
- Is centered on a problem-based learning (PBL) basis, which is more practical, relevant and connected with the real professional environments that students could experience.
- Has a wide perspective, as it is set at different consecutive courses, which can provide a more valuable and reliable information on competence acquisition.

On the contrary, some disadvantages could also be found:

- Lack of teaching research culture on the teaching community, as this protocol does not only gathers relevant information but it also requires setting a proper experimental design.
- The preparation of adequate problems to distinguish all knowledge levels, which can be a tantalizing task in some particular subjects.
- The coordination of teachers in the area of Physical Chemistry, which requires enough time and planning in advance.

3. CONCLUSIONS

Using a multi-level problem-based learning (PBL) approach, we proposed a protocol for assessing which type of knowledge seems more appropriate for competence acquisition, i.e. "know-what" (concepts), "know-how" (procedures) or "know-why" (competences). To illustrate their differences, a set of problem samples are proposed for each level in the frame of the Grades of Chemistry and Chemical Engineering. Although EHEA universities focus their teaching-learning process on competences ("know-why"), for full professional development of students a "know-how" vs. "know-what" approach has been followed, with formative "know-why" activities embedded. In this context, in a group class, two control subsets would be defined: bottom-up learning (Group 1, from "know-what" to "know-how") and top-bottom learning (Group 2, from "know-how" to "know-what"). Employing the appropriate strategies and assessment tools (i.e. teaching portfolio), the learning outcomes can be evaluated in each group to determine which starting point seems most suitable for full competence mastery. Finally, a 3 course range assessment is proposed to study the student´s

maturity effect on competence learning, where the weight of "know-how" activities is progressively increased in the latter courses.

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ANNEX 1. EXAMPLE OF MULTI-LEVEL PROBLEMS IN THE GRADE OF CHEMISTRY (SUBJECT: CHEMICAL KINETICS)

CONTENTS: Formal kinetics. Reaction rates. Reaction mechanisms.

Level I Problem (Know-What)

The reaction between hydrogen peroxide and iodide has the following mechanism:

$HOOH + I^- \rightarrow HOI + OH^-$ (slow)

$HOI + I^- \rightarrow I_2 + OH^-$ (fast)

$2\ OH^- + 2\ H_3O^+ \rightarrow 4\ H_2O$ (fast)

a) What is the overall reaction?
b) Which compounds are intermediates?
c) Predict the rate law based on this mechanism.
d) What is the overall order of reaction?

Level II Problem (Know-Why)

The reaction between hydrogen peroxide and iodide has the following mechanism:

$HOOH + I^- \rightarrow HOI + OH^-$

$HOI + I^- \rightarrow I_2 + OH^-$

$2\ OH^- + 2\ H_3O^+ \rightarrow 4\ H_2O$

What would be the overall reaction rate and order? Is there any compound that acts as a catalyst?

Level III Problem (Know-How)

The reaction between hydrogen peroxide and iodide yields iodine (yellow). Set up the required experiments for verifying the kinetics of the process, including orders of magnitude for the measured variables. Propose a reliable reaction mechanism.

HINT: a plausible reaction intermediate is HOI.

(http://www.kbcc.cuny.edu/academicdepartments/physci/pl/chm12/documents/chm12_experiment_5_kinetics.pdf)

ANNEX 2. EXAMPLE OF MULTI-LEVEL PROBLEMS IN THE GRADE OF CHEMICAL ENGINEERING (SUBJECT: APPLIED PHYSICAL CHEMISTRY)

CONTENTS: Electrochemical systems. Thermodynamics of batteries.

Level I Problem (Know-What)

An electrochemical cell is constructed using solutions of $NaHSO_4$, H_2SO_3, and $MnSO_4$ with suitable electrodes. The relevant half reactions are:

$$HSO_4^- (aq) + 3H^+ (aq) + 2e^- \leftrightarrows H_2SO_3 (aq) + H_2O, \ E^\circ = +0.17 \text{ V vs. NHE}$$

$$Mn^{2+} (aq) + 2e^- \leftrightarrows Mn (s), E^\circ = -1.18 \text{ V vs. NHE}$$

a) Sketch a working cell in which you identify the contents of each half-cell, label the anode and cathode, show the direction of electron movement in the external circuit, and indicate the direction of movement of cations in the salt bridge.
b) Write the equation for the overall cell reaction and calculate the standard cell potential.

Level II Problem (Know-Why)

An electrochemical cell is constructed using solutions of $NaHSO_4$, H_2SO_3, and $MnSO_4$ with suitable electrodes. The relevant half reactions are:

$$HSO_4^- (aq) + 3H^+ (aq) + 2e^- \leftrightarrows H_2SO_3 (aq) + H_2O, \ E^\circ = +0.17 \text{ V vs. NHE}$$

$$Mn^{2+} (aq) + 2e^- \leftrightarrows Mn (s), E^\circ = -1.18 \text{ V vs. NHE}$$

What would be the pH dependence of the potential? Are there any conditions at which the process is not spontaneous? State them.

Level III Problem (Know-How)

Could an electrochemical cell based on the next half reactions be used as a Ba(II) sensor?

$$HSO_4^- (aq) + 3H^+ (aq) + 2e^- \leftrightarrows H_2SO_3 (aq) + H_2O, \ E^\circ = +0.17 \text{ V vs. NHE}$$

$$Mn^{2+} (aq) + 2e^- \leftrightarrows Mn (s), E^\circ = -1.18 \text{ V vs. NHE}$$

State the required experiments for testing your assumptions, including orders of magnitude for the measured variables.

HINT: $K_s(BaSO_3) = 8.3 \times 10^{-7}$, $K_s(BaSO_4) = 1.2 \times 10^{-10}$.