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Investigación Educativa

DEVELOPING SCIENTIFIC THINKING SKILLS THROUGH TEACHING CHEMICAL REACTION WITH INQUIRY BASED TEACHING

Abstract

This article shows the result of implementing a series of inquiry-style activities in a first year chemistry course. The main goal is to asses the extent in which it promotes scientific-thinking skills among students, for which an experimental proposal was designed based on the course's curriculum; the selected topic was the chemical reaction. An inquiry-based class has activities with the objective of putting the students in the spotlight, allowing them to design and conduct a research based on a problem they are facing. As part of this process, students will have to compare the answers they found with those found by their peers in order to determine which the best possible answer is. By performing this sort of activities, the student's individual insight will turn to be truly meaningful. This study is based on the work done by 19 freshmen who were divided into teams who take the general chemistry course at UNAM Chemistry School, Mexico. The elements of the work done by students that are presented in this article are the inquiry questions, predicted outcomes, a contrast between the expected and the results, a designed experimental procedure, conclusions and the answers found for the original question.

Keywords: Chemistry lab, inquiry-based teaching, scientific thinking skills

DESARROLLO DE HABILIDADES DE PENSAMIENTO CIENTÍFICO A TRAVÉS DE LA ENSEÑANZA DE REACCIÓN QUÍMICA USANDO LA INDAGACIÓN

Resumen

Este articulo muestra los resultados de la implementación de actividades de indagación en un grupo de Laboratorio de Química General. El objetivo fundamental es evaluar el grado de desarrollo de las habilidades de pensamiento científico entre los estudiantes, para lo cual se diseñó una propuesta experimental basada en el temario de la disciplina, el tópico seleccionado fue Reacción Química. La idea es promover un aprendizaje basado en indagación en donde los estudiantes deben dar respuesta a un problema de investigación y donde se promueve el trabajo colaborativo de tal forma que se alcance una estrategia conjunta. Al realizar este tipo de actividades, la percepción individual del estudiante se convertirá en algo verdaderamente significativo. Este estudio se basa en el trabajo realizado por 19 estudiantes que cursan la asignatura de Laboratorio de Química General de la Facultad de Química de la UNAM, México. Los elementos del trabajo realizado por los estudiantes que se presentan en este artículo son las preguntas de consulta, los resultados previstos, un contraste entre lo esperado y los resultados, un procedimiento experimental diseñado, conclusiones y las respuestas encontradas para la pregunta original

Palabras clave: Laboratorio de Química, enseñanza basada en indagcación, habilidades de pensamiento científico

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Introduction

By allowing freshmen to engage in an inquiry-based experiment during their Chemistry course lets them increase the interest and significant knowledge acquired during the foretold course. Some of the most commonly used strategies for achieving this goal includes the use of technical language, just like an actual scientific researcher would do, demanding of the students to explicitly explain what they plan to do in the lab and how they will make use of the lab equipment, and highlighting the importance of the results obtained during the experimentation process (Eichstadt, 1992).

Nevertheless, we meet a linguistic discussion whenever "inquiry" is mentioned; since Philosopher John Dewey first brought it up in 1910 it has been subject to diverse interpretations (Reyes, Padilla, 2012; Lara-Mendoza, 2015). As far as this article is concerned, the 1996 National Research Council definition will be taken into consideration since it is widely accepted: "*Inquiry is a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyse, and interpret data; proposing answers, explanations, and predictions; and communicating the results*."

The goal of every inquiry-based class is to enhance scientific thinking among its students. This term has also been subject to numerous definitions, yet experts seem to have reached an agreement regarding some of its traits.

An Experimental Course Based on Inquiry tivities

Scientific thinking is defined by Kuhn (2010) as a human activity that means it is something people do, not a feature they have. It is linked to one´s rational thinking and problem solving abilities. Its goal is the search of knowledge.

If our intention is to consider scientific thinking as a human activity, we most take into consideration that as children, we make an early attempt to build explanations for the physical and biological phenomenon's we experience. These explanations are called "theories" and often have the common trait of being inaccurate or naive, since they do not fully explain the event they intend to describe. This is because the "theories" are subject to the academic and social background due to the individual enouncing them (Yan and Talanquer, 2015). So that, it will be absolutely necessary to continuously assess these theories as new experiences that enriches our minds, and see if they successfully explain the phenomena we are experiencing.

Carmel et al. (2015) state that scientific thinking can be defined as the foundation of basic reasoning like analysing data or formulating a hypothesis. He also states that scientific thinking can be reinforced via an inquiry-based class. In opposition, Domin (1999) collected pedagogical theories from the late 20th Century; he established a chart of the cognitive skills that take place in an inquiry-based class, as well as the situations where students use them.

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The cognitive skills mentioned by Domin (1999) can be divided into two groups: low and high, based on the cognitive demand they represent (see Table 1). The three at the bottom (analysis, synthesis and assessment) are considered as high cognitive skills; which intervene when the class is based on inquiry activities.

Cognitive Skill	Definition	When is it use?
Knowledge	Remembering the previously learned concepts.	Defining a concept, identifying an object, establishing the steps for a procedure.
Comprehension	Keeping in mind the meaning of the concepts.	Explaining a concept, interpreting a chart.
Application	Using the new concepts en concrete situations.	Solving a problem, building a chart, using a concept in a new situation.
Analysis	Decomposing the concept in its parts.	Detecting relevant information, establishing relations between the concepts.
Synthesis	Uniting the parts for coming up with a new concept.	Enouncing hypothesis, coming up with an experimental procedure, suggesting alternatives
Evaluation	Establishing the quality based on established criteria.	Grading the experimental results, drawing conclusions.

Table 1. Domin's chart for ranking the cognitive skills students employ (Domin, 1999)

As these experts pointed out, a science class based on inquiry activities can, indeed, lead to the students improving their abilities to solve problems and think rationally. In order to achieve so, the NRC (1996) established a series of steps that allow teachers to make sure their class is following the recommended structure. Previously mentioned, steps go as follows:

1. Establishing an initial question for the research.
2. Gathering evidence.
3. Formulating explanations based on the experimental evidence in order to answer the original question.
4. Appraising the explanations
5. Sustaining the foretold explanations before peers.

Following this series of steps should allow students who are taking the class to improve their scientific thinking skills, yet some experts (Couso, 2014) warn us about the risks of "simplified" versions of this class structure. Some of the most frequent mistakes when adapting these steps to a classroom are:

- Assigning tasks aimed to engage students merely on a technical level, instead of those of intellectual nature.

- Forcing the class to become a "fun science" class. Making the class content interesting for student's doesn´t mean they get to cut out all the concepts, laws, models that they must learn during class.
- Conducting researches on topics not included in the curriculum. Just because a research can be conducted on a given topic, it doesn´t mean it is relevant for the class context.

When properly integrated in the classroom, this series of steps will lead to an increase in the students abilities commonly linked to scientific thinking, such as: proposing the adequate questions to start an investigation, formulating a hypothesis, scheming and following an experimental procedure, analysing the experimental data and drawing conclusions (Hofstein, et al. 2005).

So far, this document has centred itself on establishing the goals per suited by a science class based on inquiry activities, these goals are clearly opposite to the usual development of a traditional style science class. Which is described by Domin (1999) as follows:

- Students are expected to follow the instructions given by the teacher. Therefore, they should get the same results as their classmates.
- Since all students are performing the exact same procedure, experienced teachers should be able to identify their mistakes easily.
- Grades are often granted based on the comparison of the obtained results against the expected results.

According to Domin (1999), these types of classes represent a lower cognitive set of skills from students. There are many ways for teachers to take up inquiry activities into their classrooms. Some experts have come up with their own scales based on the amount of inquiry taken during a research in any given class.

Marshall D. Herron designed the most famous of them all in 1971. In it, Herron divides a research in three major components: the question that conducts the whole activity, the development of the research and the answer found to the preliminary question (Del Carmen, 2000). Researches are ranked based on who is responsible for establishing each of these components; the level 0 researches are those in which teacher establishes all three components. In opposed to, researches in which students define each of the components. Those will be ranked as a level 3 (see Table 2).

Level	Question	Development	Answer
0	Teacher	Teacher	Teacher
1	Teacher	Teacher	Student
2	Teacher	Student	Student
3	Student	Student	Student

Table 2. Classification chart designed by Herron in 1971 (taken from Del Carmen, 2000)

All subsequent scales are based on the one proposed by Herron that is also the case of one designed by Caamaño (2003). This author establishes six components for any given research (Table 3). He also ranks them based on who is responsible for establishing each one of them. In this case, he said that the most common experimental work done at school is in level 1, but as teachers we should try to move towards higher levels, because scientific thinking skills are developed most in such levels.

Component	Degree of Openness					
	1	2	3	4	5	6
Subject of Interest	T	T	T	T	T	S
Stablising the problem	T	T	T	T	S	S
Planning	T	S	S	S	S	S
Setting a strategy	T	T	S	S	S	S
Doing the experiment	S	S	S	S	S	S
Results interpretation	T/S	T/S	T/S	S	S	S

Table 3. Caamaño's proposal for ranking the "openness" of a research. (T=teacher; S= student) (Caamaño, 2003)

Another proposal was made by Buck et al. (2008), which also follows this structure. They also establish six major components for any given research and ranks them in levels based on who is responsible for providing each one of them (see Table 4). Only Domin (1999) came up with a different proposal (Table 5). Instead of establishing a rank, he describes the diverse existing styles for teaching an experimental course as well as their main features.

Component	Level 0	Level 1/2	Level 1	Level 2	Level 3
	Confirmation	Structured Inquiry	Guided Inquiry	Open Inquiry	Authentic Inquiry
Problem / Question	T	T	T	T	S
Theory / Background	T	T	T	T	S
Procedure / Design	T	T	T	S	S
Results Analysis	T	T	S	S	S
Sharing Results	T	S	S	S	S
Conclusions	T	S	S	S	S

Table 4. Classification chart designed by Buck, et al. (2008)

When taking a traditionally styled class, students are assessed based on their lab reports or pencil and paper exams; however, as Hofstein, et al. (2005) stance, the information provided by this sort of documents is limited because it doesn´t take into consideration the students 'development.

Instruction Style	Main Features
Expository	Comparing results
Inquiry	Establishing a problem, proposing a solution, predicting the outcome
Discovery	Getting to a previously-wanted result
Problem Based	Designing comparable hypothesis

Table 5. Domin´s instruction-styles classification chart (Domin, 1999a).

Assessment

It's only fair that a different type of class has a different method of assessment. That's why; Hofstein (2004) highlights the importance of the right use of procedures and techniques while making this sort of assessments. A foretime, students had been evaluated with exams and reports, however Hofstein (2004) said that these tools offered limited knowledge acquirement, which is in no way helpful to the students' development of scientific thinking.

In this sense, we wanted to evaluate two elements related to students lab work. The first one is the kind of explanations that they built when observing a phenomena, under the chemical models. The second is if they could learn the studied concepts.

According to Chamizo and Izquierdo (2007), the best formula for assessing students in an inquiring styled class is the heuristics diagram which allows them to keep their solving process well organized, giving them the opportunity to state why they have chosen that particular solution among many other possibilities as well as giving major importance to the data obtained during the experimentation for drawing conclusions.

To assess how students implement the scientific thinking skills we used a modified version of heuristic diagram (see appendix 1), which is "an improvement of Gowin's Vee, following Toulmin's philosophical approach" (Chamizo, 2012, p. 750). This outline is a graphic organizer that helps students represent the thinking process they go through when they think about the phenomena, questions, theory (applications, concepts, models), methodology (data collection, data processing, conclusion), answer, references.

Teaching chemical reactions

According to a research conducted by Maeyer and Talanquer (2013), students face big difficulties when trying to explain and predict the outcome of a chemical reaction, mainly because of the big challenge that understanding the relationship between a substance´s macroscopic properties and what its microscopic structure is.

Chandrasegaran et al. (2011) bring back Johnstone´s idea stating that the difficulty students face while making explanations about chemical reactions is due to the lack of abilities they yet have to develop to make descriptions considering three different levels of representation:

- Macroscopic. A substance´s properties they get to work with during the experimental course
- Microscopic. The structure and composition of the given substance
- Symbolic. The symbols used for describing a reaction.

For students to make a complete and correct explanation regarding a chemical reaction, they are demanded to use all three levels of representation, just like experts do. This is the big challenge they face whenever they are asked to complete this task.

Another major cause, of this type of common mistakes, has been pointed out by Balocchi et al. (2005) when students are trying to learn a new subject: the alternative conceptions. These are described as naïve explanations, which do not add up to those widely accepted by the scientific community; they do, however, add up quite well inside the student's mind, which makes them so hard to identify and remove (Wandersee, Mintzes and Novak, 1994). Balocchi et al. (2005) made a literature review and found a group of alternative conceptions related to students' learning the chemical reactions. These authors claim that there are at least five kind of alternative conceptions related with chemical reactions. The first one is the idea that substances have human qualities (animism) that is associated with what Talanquer (2007, 2013) said that students often

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give explanations. The second idea is called "disappearance" because students think that substances disappear during the chemical reaction. The third one is the "displacement" when one substance displaced by another. The fourth is the "alteration" when a substance's identity remains unaltered, even though its appearance and properties have change. Finally, "transmutation" that is related with the idea that one substance can be transformed into energy.

According to Maeyer and Talanquer (2013), the best way to teach chemical reaction is to ask students to make use of the symbols used to describe chemical equations in order for them to be able to make better descriptions of the studied reactions. It is through constant practice that students will develop the ability to make better predictions and describe more accurately the reactions they are studying.

After this entire framework we can say that the goal of presenting these scales is to integrate this study in all of them, based on the work done by students. This work will be described thoroughly later, but for this moment, it will have to enough with the ranking presented in table 6.

Author of the Scale	Rank Granted
Herron	2
Domin	Discovery / Problem Based
Caamaño	4
Buck et al.	2-3

Table 6. Assigned classification of this research according to each presented proposal.

The main goal of this study was to design a proposal based on inquiry activities for the General Chemistry Experimental courses taught at the UNAM School of Chemistry.

Research questions

As a consequence of, our research question will be to determine whether this sort of experimental work would help to develop scientific thinking skills in the students taking part in it. Among the desired skills for students to develop were: enouncing inquiry questions, making hypothesis and predictions, scheming experimental procedures, analysing and interpreting the obtained data, building explanations for the observed experiments, making them aware about their own level of knowledge.

Methodology

This study was held at National Autonomous University of Mexico (UNAM) School of Chemistry during the 2015 Fall Semester. It presents the work done by 19 freshmen for their final assignment in their experimental General Chemistry course. The subject studied was the chemical reaction, which belongs to the fourth of the five units in the course. This research is qualitative, and we will analyse data got it from different activities that were done by students. However, due of space reasons, in this paper we will show just the results of two teams of two members each, and some examples from others. But, we will not show the results from polymers activity. The teams were chosen based on the kind of answers and the differences among each other. One example of heuristic diagram filled out by students that are showed in the appendix.

The empirical work is done to encourage students to develop scientific thinking skills. Usually this is the first time students openly think about these skills, so they have to learn to ask questions, to formulate predictions or hypotheses, propose an experimental design and to recognize the models they are using.

The implementation was done in four sessions of two hours each one. Previously, they have to look for the theory, regarding to what a chemical reaction is, how they could recognize that chemical reaction was taking place, which types of chemical reactions are there, etc. So, in the first session, with the homework done, students had to formulate their inquiry question and design an experimental procedure. In the second, they continued with the design and move on to formulating their own hypotheses, predicting what they expected to observe in their experiment. In third and fourth sessions, students conducted their experiments; gathered data and assessments are made. Chemical nomenclature was studied through the whole period previous to implementation.

Designed Activities

In table 7, it's shown the actual activities that were presented to the students as part of the Chemical Reaction class. As we can observe, there are three problems. In the first one, they have to propose at least one chemical reaction using as a background their bibliographical research. In the second one, they have to identify one substance using chemical reactions, and in the last one they have to synthetize a polymer.

1. You will choose some (as many as you think you may need) of the following available substances and write at least one reaction for every possible kind, according to the research done prior to the class. Make sure you are fully covering the three main classification criteria's. Also make sure you make accurate descriptions of the reactions you are proposing. Available substances: Ionic Compounds. $CuSO_4$, $CuCO_3$, $CaCl_2$, NH_4NO_3, $Ba(OH)_2.8H_2O$, HCl, NaOH, NH_4OH, Metals (Zn, Na, Cu, Ca), Non-metals (C_n, S_8)
2. An unidentified substance will be handed to you. Your task is to come up with an experimental procedure that includes chemical reactions, that allows you to successfully identify the given substance. Do not forget to make complete and accurate descriptions of what you saw when conducting the chemical reactions. The substance you have been given is one of the following: $CuSO_4$, $CaCl_2$, $Ba(OH)_2$
3. Chemical reactions are widely used in an industrial context, for example, when a specific substance must be synthesized for a particular process. Polymers are a very appreciated group of substances due to their multiple uses and applications. Listed below are some common polymers. Our task will be to look up some of their most frequent uses and how they can be synthesized in the lab. Choose one of them and synthesize it. Phenol-formaldehyde polymer or Urea-formaldehyde polymer

Table 7. Activities developed with students in the inquiry lab.

Results

This section contains the actual outcome of presenting the schemed activities to the students. It shows the results obtained by two of the teams that took part in this study; they will be used as an example to describe the quality of the work done by the teams.

Questions: According to Chamizo and Izquierdo (2007) there are three types of questions: closed, semi-open and open. The first one could be answered with one word or a small phrase, the open questions are those where a research is required, but some times it is not easy to answer. The semi-open questions are those that required a research, but the answer is easy to get. In this case, we expected that students could ask semi-open questions with just one requisite: these ought to be answered with an experimental proposal.

The disparity on the development of the skill of asking appropriate questions for conducting a research can be explained through some ways like the academic background of each student or the extent to which they got involved in the activity.

Regardless to which profundity each student managed to develop his or her ability to ask better questions, it must be highlighted that all questions had a series of traits: none of them could be answered with neither "yes" nor "no" or with any other single word; the answer to these questions could not be found by looking it up in a single source. It is because of this series of characteristics that these questions can be considered "semi-open".

So, students have to identify the phenomena, given to them, and after that, they must ask the inquiry question, *id est*, the question that will conduct the whole research during class. As we have said we will show just the data gathered from two teams:

Team 4. Q1. What chemical reactions could be done in order to observe the following type of reactions: neutralisation, acid-base, decomposition, double displacement, redox and synthesis? Q2. What is the macroscopic-evidence expected to see in order to assure the chemical reaction has occurred?

Team 8. How could we identify a substance through chemical reaction?

The questions inquired by members of team 4 can be classified as well structured since they express the context in which they expect to find an answer for each one of them. Both are semi opened and require an experimental design to answer them. In the structure of the questions it is notorious that these students investigate in literature the types of chemical reactions and how to make them.

On the other hand, the question asked by team 8 shows that its members understood the task that was assigned to them, but doesn´t really show if they have a plan for finding an answer. Additionally, it seems that such questions do not require an experiment to be answered. So, we could say that it depends on what students interpret of it, so it could be closed or semi-opened. In general, students tend to ask semi-open questions, but very few of them really ask questions that could be answered throughout an experimental design, as it is required in lab.

Hypothesis and experimental design: After they were asked the questions, they were asked to propose some chemical reactions, but they would have to predict the outcome (table 8). The main idea is for students to think about the change of properties related with the forming of the new substances.

Team 4 mentioned some phenomena that couldn't indeed be observed or measured within the context of the class, like the interchange of protons or electrons (which is part of the model). They described the explanatory model quite well, but it is not what they are going to observe. In the first reaction, however, did point out that a change of colour is expected as identifying evidence they will need to tell the chemical reaction that has occurred. But they did not mention the expected colour or if they will require or observe something else.

Team	Intended Reaction	Expected Evidence
4	$CuCO_3(s) \rightarrow CuO(s) + CO_2(g)\uparrow$	A change of colour is observed in the substance. (In decomposition reactions one substance spreads into 2 or more simple substances)
	$2HCl(aq)+Zn(s) \rightarrow ZnCl_2(aq)+H_2(g)$	In a displacement reaction an element substitutes another in a given compound. Zinc is found in an elemental state (with a correspond oxidation number cero) ends up bonding either to chloride. Zinc acquired two positive charges by the loss of two electrons, gaining an oxidation number +2. The element that goes through oxide, and which oxidation number rows, looses electrons.
8	$8Zn(s)+S_8(s)\ \Delta\rightarrow\ 8ZnS(s)$	During the reaction, white flashes will be seen.
	$HCl(aq)+ NaOH(aq) \rightarrow NaCl(aq)+H_2O(l)$	When we add up the second substance to the first, which already contains the indicator, we will begin to notice how it´s colour changes according to the rate at which the second substance is added up. One case would be to have the hydrochloric acid containing the indicator; it will turn green as sodium hydroxide is added.

Table 8. Reactions conducted by teams 4 and 8 along with the evidence they expected to see.

Team 8 really managed to stand out the evidence they expected to find when conducting these reactions, like a change in colour or the appearance of white flashes. Besides, in the second reaction they recognized the use of the acid-base indicator to know if this is having an effect.

After they formulated their hypotheses, students proposed materials and the amounts of substances they would need to conduct their experiments. Hence, they had to observe and handwrite on their notebook all the data they got.

The main goal was for students to be able to predict what they would observe in lab, some teams made predictions to how the phenomena is explained, which means the model. One example is the prediction of team 4 in the second reaction when they said "*Zinc acquired two positive charges by the loss of two electrons, thus gaining an oxidation number +2*" another example was given by other team who said "*when Zn loss electrons, copper won them*". This kind of predictions tells us something about the concepts students are learning and the models that allow them to explain the phenomena. In spite of this, we could say as well as Maeyer and Talanquer (2013) that they are having problems identifying and distinguishing matters of macroscopic properties and its relation with its structure or composition. So, this chemical thinking skill is quite difficult to acquire for students.

Another poor habit that was found in the students' predictions was that they classify the chemical reaction that they are proposing. For example, one team said that "*would observe a simple displacement reaction*" or synthesis or neutralization, etc. This preference to make predictions around classifications might be explained by the students' academic environment and because the subject was already studied in theory class.

As previously mentioned, alternative conceptions are one of the elements that hinder the learning process related to chemical reaction. Some of them were founded in this section and we are mentioning just some examples. One of the teams shows some classical examples of "animism" conception when they said, "*Cu is less active than Zn*" or "*Zn is more active than H*". Meanwhile, one of the teams used the "Disappearance" conception when they assured that "sodium is consumed" a singular thing is that the same team was dubious about their claim.

Another interesting alternative conception that was found in a team was "Displacement", for example one team said, "*the hydrogen of acids are substituted by zinc*", other team said, "*the displacement of metal (Zn) by the other [metal] that it is in the salt ($CuSO_4$)*". In this last example two alternative conceptions shown is, displacement and animism, when students said that one metal is in the salt.

We can say that not all the hypothesis or predictions had alternative conceptions or mistakes, many of them were written correctly, because they described macroscopic manifestations of chemical reactions. According to the experimental design, students were asked to propose materials and terms that could help them develop their experiments. They have measure the mass or volume from substances and solutions that they must use. We are just showing some examples of the students' proposals (table 9).

Team	4	8
Experimental proposal	Add 1 mL of HCl(aq) to the problem sample, if macroscopically nothing happens we will identify that it is $CaCl_2$; if something happens we will add the universal indicator and if this turns red we will have $CuSO_4$, if it turns blue we will have $Ba(OH)_2$.	Add some drops of ammoniac to a solution of copper sulphate. The product that will form is tetra-ammine copper (II). This product is heated until a precipitation is formed.
		We will add some drops of phenolphthalein to a saturated dissolution of barium hydroxide, a change of colour will be observed.
		In a test tube with $CaCl_2$, 1mL of sulphuric acid will be added. If we have $CaCl_2$, this will be dissolved and it has to conduct electric current.

Table 9. Examples of experimental proposals for problem 2.

The team 4 used a qualitative criterion of pH, they think that with this one they could identify the substance problem. We can see that there is a mistake here, because they had $CuSO_4$, this substance is blue and its dissolution too, so if they use universal indicator they will see nothing related with its criterion. The team 4 make use of the background, because they had been done something similar in a previous practice. They propose a diagram to identify the substance's problem. (See Figure 1)

Data gathered: In this section, it is shown what students actually claimed to have witnessed when conducting the experiment the reactions (see table 4), as an attempt to compare the evidence they originally expected to find to what they obtained in reality. Students were asked to describe all their observations beginning with the description of the system before, during and after the chemical reaction. They have to make those descriptions and compare with the predictions done previously. So, they could see similarities and differences among them.

Members of team 4 faced a contrast between what they expected to see and what they actually encountered when conducting the reactions. Nevertheless, they successfully pointed out the macroscopically evidence that led them to conclude the wanted reactions, in fact, happened for each one of them.

Members of team 8 also pointed out macroscopical criteria for acknowledging a reaction has concluded, like a change in colour or the formation of a new material. However, they show some traits of a misconception, since they declared one of the materials (zinc) disappears.

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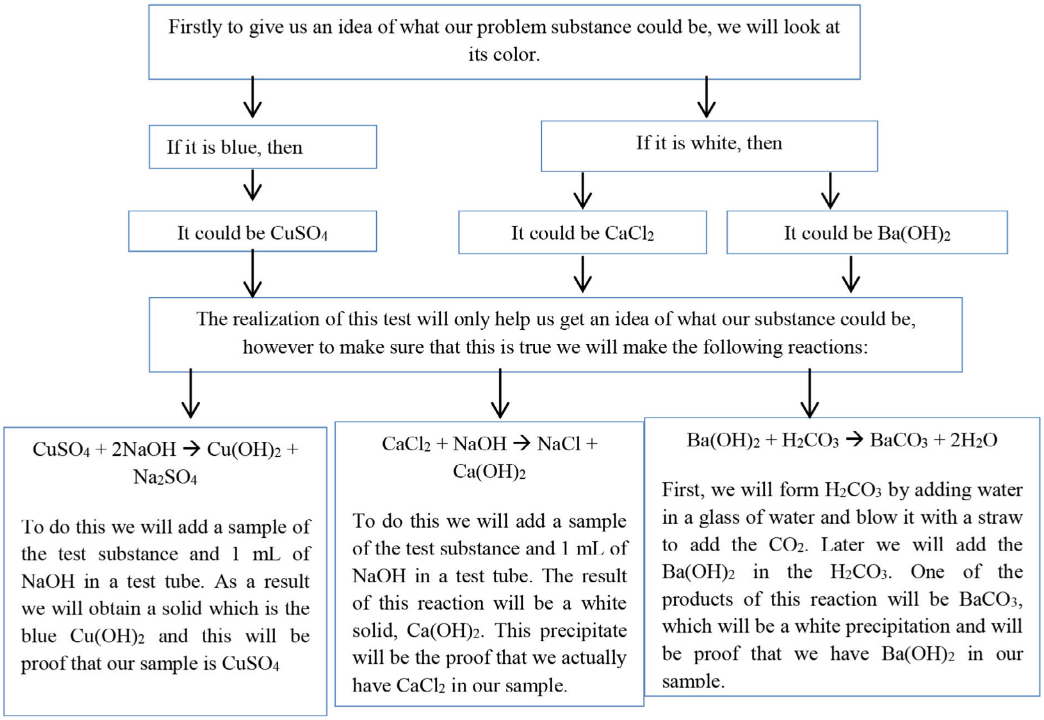

Figure 1. Example of students diagram to solve their second problem

In some of the teams prevailed the idea of classifying in terms of the kind of chemical reaction instead of making a macroscopic description of the changes they were observing. For example, team 2 did this but they make amends when mentioning the use of indicator or formation of precipitate as evidences that a chemical change has happened. However, the alternative conception related to displacement in zinc and hydrochloric acid is consistent with their predictions. Another team in which prevailed the alternative conceptions was team 3; they showed *animism* and *displacement* when they assure that "*Zn is capable to displace the hydrogen*" because it is "*more reactive*" and that "*the water molecules (…) are replaced by* NH_3 *molecules*".

In general, students developed the skill of describing the macroscopic phenomena that was observed and that permitted them to assure that the chemical reactions had occurred (Table 10). However, we could say that their development is far from being called "uniform" among teams, mainly because some observations were found with mistakes or alternative conceptions.

Conclusions: After conducting these reactions, students were asked to draw conclusions based on their discoveries, because one of the goals of this way of teaching is for students give more emphasis in their data to build explanations to the observed phenomena. We were trying to make them modify those incomplete or naïve explanations that they used to have when they started the lab work. A few examples are the following:

Team 4: Chemical reactions are transformations, some of which are very complex or have the need of very specific conditions in order to happen. So, you must take into consideration all possible variables that may affect the reaction in order to actually get the desired product.

Members of team 4 highlighted the importance of the conditions on which a reaction occurs, and how even the slightest variation may affect the quality of the product you are attempting to obtain.

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Team	Reaction	Observations
4	$CuC0_3(s) \rightarrow CuC0(s) + C0_2(g) \uparrow$	When the $CuCO_3$ was heated, you could see it go from blue to black; it didn´t take much time for the reaction to happen.
	$2HCl(aq) + Zn(s) \rightarrow ZnCl_2(aq) + H_2(g)$	You could see bubbles coming out when HCl (aq) was added to the Zn. It must be H_2 (g), as predicted; however, the change in colour from grey to white could not be seen.
	$HCl(aq) + NaOH(aq) \rightarrow NaCl_2(aq) + H_2O(l)$	A basic value for pH was obtained for a mixture containing 0.5 mL of NaOH (aq) and 0.5 mL of HCl (aq), indicating the concentration for NaOH (aq) and HCl (aq) wasn´t the same. HCl (aq) was added drop by drop until a neutral pH value was obtained.
8	$HCl(aq) + NaOH(ac) \rightarrow NaCl_2(aq) + H_2O(l)$	NaOH (aq) was added to a mixture containing HCl (aq) and a pH indicator. As the NaOH (aq) was added, the mixture went from red to green.
	$Zn(s) + 2HCl(aq) \rightarrow ZnCl_2(aq) + H_2(g)$	When HCl (aq) was added to the Zn, it started bubbling until zinc completely disappeared
	$2H_2O_2(aq) \xrightarrow{catalase} 2H_2O(l) + O_2(g)$	As soon as H_2O_2 was come in contact with blood, foam started to form.
	$Cu_2SO_4(s) + 2NH_4OH(aq) \rightarrow 2CuOH(s) + (NH_4)_2SO_4$	When H_2O_2 was put in contact with the solution containing sulphate, it´s blue colour started to turn brighter. Soon after, a solid was formed.
	$8Zn(s) + S_8(s) \xrightarrow{\Delta} 8ZnS(s)$	Sulphur melted quickly when heated directly with the Bunsen burner. It took a while for the reaction to happen, but when it did, sparkles were seen.

Table 10. Observations of teams 4 and 8 based on what they actually saw when conducting the reactions they suggested.

Team 8. We can sum it up by saying chemical reactions are highly important because they can be found in daily phenomena, since they are the founding for basic vital functions. We managed to confirm the described behaviour for the corresponding reactions, allowing us to clearly classify and identify them based on their behaviour.

Members of team 8 pointed out how they are now able to identify and classify reactions based not only on the described behaviour in literature, but also on the actual changes they witnessed in the lab. Both teams started this part by highlighting the importance of chemical reactions on daily events.

Every team highlighted different elements in their conclusions; however, there are some common factors that let us distinguish what things caught the students' attention when they studied the chemical reactions. So, one fundamental idea was that students consider relevant the fact that it would be possible to find chemical reactions in everyday

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phenomenon. In this sense, at least four teams claim that those reactions are very well described in specialized literature, and by starting from this point they were able to make lab predictions.

One interesting conclusion comes from team 9, when they said: "*Every reaction is produced from having reagents from which after an experimental process is possible to get products. But, this kind of reactions comes from theoretical models that were built from classify every similar chemical reaction*". This is a very interesting conclusion, because students managed to identify the idea of how models are built, at least from the classification of chemical reactions.

These are only a few simple examples of the work done by the students. The quality of this splitting into different teams is pretty much the same; they all have alternative conceptions as well as valuable contributions in terms of the evidence they expected to find and the explanations built for them. For a simpler analysis, a fragment of the heuristic diagram done by one of the teams was added at the end of this article.

Discussions and implications

According to Zimmerman (2007), scientific thinking skills could be learned easily by children, it all depends on the teaching strategy used by the tutor. In our case, most of our students never had developed any of these skills, at least not with this name, besides they are almost adults and some times it would be more complicated to learn it from them. However, we consider that it is in fact possible to promote scientific thinking skills among college students when they are taking part in an experimental course based on inquiry activities. Despite this, we can say that there is a high level of differences among the skills developed by students, and we think that this depends on their own background.

Fundamentally, the level of achievement that students had was directly related to the level of commitment they demonstrated; which was reflected in the quality of the concepts they had to research before starting the experimental activities, how they approached their inquiry question, the careful design of an experimental procedure and formulation of proposals to improve the work realized, as well as the report done, like the heuristic diagram. This claim is not trying to put the whole responsibility of success or fail on students; it will be naïve to ask a high level of achievement without a big responsibility; it means that teaching based-inquiry requires that very committed teachers and invested in implementing this kind of approaches. To do that, it is not enough to have a complete domain of content, but to be capable of introducing such content in a creative and innovative way, constantly designing activities that present a challenge for students. At the same time, it is necessary to assess in a different ways, which means to assess not just the acquired content but also the grade, the scientific thinking skills that you would want the students to develop.

The work done by students in the chemical reaction experiment shows that it is possible to develop skills like asking questions that can be used to conduct a research in the lab. We can say that it is possible for students to make predictions of what would happen around their experimental proposals, using a macroscopic explanation. Even in a chemistry course, sometimes pointed out by the disciplinary and rigidity of its curricular content, students were capable of making use of their creativity to design an experimental procedure to solve the problems they have to deal with. In this way, some students even assured that they could show the existence of a relationship between the concepts and models that explain those phenomena that we called chemical reactions.

As we have said, students got different levels of scientific thinking skills developed. These results can be considered as expected, because the complete development of these skills must be result of a constant use of this. Another important point is that the progress should be reflected on both, students and teachers. Students must realize which ideas they do not understand or what concepts where showing alternative conceptions. Teachers must reflect about the whole process, thinking about the students' problems as well as those in which themselves had some difficulties. A teacher struggle, that we have identified, is that they´re used to feeling that have failed with themselves and students, because when they are starting the implementation with this approach, they think they cannot give answers or explanations.

Implementing teaching based in inquiry involves a big commitment that must be made in terms of lab, equipment and time, by all the faculty members taking part in it. A big amount of resources must be employed and a big deal of planning in order to allow students to get a proper feedback regarding the quality of their work.

Long-term benefits from this type of instruction style will only be clearly demonstrated when said foretold is used in other experimental courses during the student´s time at school. It is important to consider that the inquiry should be worked since the beginning of the school period. In our case, students have already developed all scientific thinking skills throughout the whole semester, and when this experimental work was implemented. Other important aspect that helped them was the heuristic diagram. This one is structured to allow them to think about the skills in an independent way (see appendix 1).

We found that the use of heuristic diagram permit students to identify when they are doing progress related to the skills we wanted they develop. In this case, the diagram is structured to identify at least five elements related to scientific thinking skills: phenomenon, questions, theory (concepts, applications and models), methodology (experimental proposal, data collected, data analysis, conclusions) and the answer to the question. The main idea is that students could recognize that their answer must be the response to their question and that the whole diagram is entirely consistent.

The process of constructing a diagram is not easy, much less if students are not to get used to it and they have not been thinking about the scientific thinking skills. As we have said, it is necessary that this learning would be a long term process, and to start with how they ask questions in the way they could identify the kind of questions they are asking. Moreover, they must recognize if their experimental proposal will help them to answer their question.

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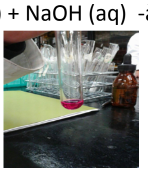
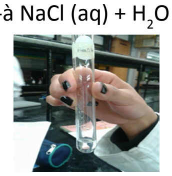
Appendix 1. Fragment of Heuristic Diagram

<table>
<tr><td colspan="2">Heuristic diagram about: Chemical reactions</td></tr>
<tr><td colspan="2">A) which phenomenon am i interested to study?
Chemical reactions</td></tr>
<tr><td colspan="2">B) What are the questions i am interested to answer?
1. When some chemical reactions are proposed, how can we identify that they really happen?
2. From the three different substances, what would experimental proposal let us to identify them through chemical reactions?
3. Which would be the experimental design to synthesize phenol-formaldehyde in the lab?</td></tr>
<tr><td>D) theory</td><td>C) methodology</td></tr>
<tr><td>D1) What concepts will help me to understand the phenomenon?
Chemical reactions
(here students made a description of types of chemical reactions as well as what are and how are synthesized synthetic polymers</td><td>C1) Which is the experimental process that will help me to answer my questions?
Students describe what are they going to do in their experiments</td></tr>
<tr><td>D2) Are there other phenomena that I could understand with these concepts? (Applications)
Synthesizes of medicines
Mineral purification</td><td>C2) How should I process my data?
HCl (aq) + NaOH (aq) -à NaCl (aq) + H_2O (l)
With this reaction we hope to see neutralization. So, we will add 1 mL of NaOH (aq) 0.1M in a test tube and also a drop of phenolphthalein. After that we add 1mL of HCl (aq) 0.1M.
Phenolphthalein is a pH indicator, which is pink in basic and colorless in acid. This change of color will help us to see the chemical reaction.</td></tr>
<tr><td>D3) Is it possible to build a theoretical model with my experimental data? Why? Which?
The theoretical models are the chemical equations. One example is:
HCl (aq) + NaOH (aq) -à NaCl (aq) + H_2O (l)
 </td><td>C3) Analysis and conclusions from experimental data
HCl (aq) + NaOH (aq) -à NaCl (aq) + H_2O (l)
What we observed was that adding phenolphthalein to 0.1 M NaOH (aq) turned a pink color, which indicated that we were actually working with a base. After adding 1 ml of HCl (aq) to the NaOH (aq) preparation, we saw that indeed the pink color disappeared and the solution became colorless, which was gross evidence that the neutralization was effected.</td></tr>
<tr><td colspan="2">E) which are the answers to my questions?
1. The macroscopic tests that allowed us to determine that effectively our reactions were carried out were the change of coloration or the detachment of a gas, or the formation of a precipitate.
• coloration: as in the neutralization reaction, where phenolphthalein helped us to better observe this phenomenon, while in the universal indicator we were able to ensure that when reacting Na with H_2O a base is obtained.
• gas evolution: as in the reaction of Zn with HCl (aq) or Na with H_2O, where a bubbling was observed and could be a test of H_2 evolution.
• formation of a precipitate: in the reaction of $CuSO_4$ with NH_4OH, where we could observe that a substance insoluble in water that is $Cu(OH)_2$ was formed.
2. Following the experimental procedure proposed we were able to determine that the test substance that we had was $CuSO_4$, since in carrying out the tests raised we obtained what we had predicted and that certainly helps us to ensure that $CuSO_4$ was the substance we were looking for.
3. Following the experimental procedure proposed above, we obtained a sample of the polymer that we wanted and that complied with the characteristics of our predictions</td></tr>
<tr><td colspan="2">F) References</td></tr>
<tr><td colspan="2" align="right">Self-assessment (total points)/29</td></tr>
</table>