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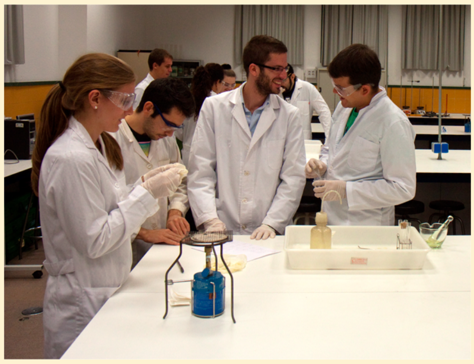
Introducing Inquiry-Based Methodologies during Initial Secondary Education Teacher Training Using an Open-Ended Problem about Chemical Change

Iñigo Rodríguez-Arteche and M. Mercedes Martínez-Aznar*

Departamento de Didáctica de las Ciencias Experimentales, Facultad de Educación-C.F.P., Universidad Complutense de Madrid, Rector Royo Villanova, s.n., 28040 Madrid, Spain

Supporting Information

ABSTRACT: In this paper, the characteristics of an initial training program for secondary school physics and chemistry teachers are presented. This program is based on the resolution of professional problems, in order to develop preservice teachers' competencies for integrating inquiry-based science education (IBSE) into their future teaching. With this goal in mind, the methodology of problem solving as an investigation was introduced, and preservice teachers had to solve a sequence of open-ended problems using this IBSE-type methodology. The article describes how they solved the practical problem "What might happen when two substances are placed in contact with each other?" with a specific focus on the roles of both the students and the professor. Moreover, the paper provides guidelines for implementing the problem, which is compatible with the curricular content of secondary education. Finally, an analysis of preservice teachers' written reports about the problem suggests that the procedures which they found more difficult were those involved in the stages of "design of resolution strategies" and "analysis of results".



KEYWORDS: *Graduate Education/Research, High School/Introductory Chemistry, Inquiry-Based/Discovery Learning, Problem Solving/Decision Making, Constructivism, Student-Centered Learning, TA Training/Orientation*

INTRODUCTION

The Inquiry-Based Science Education (IBSE) approach consists of a learner-centered, constructivist perspective of learning. These IBSE methods provide students with a challenge or problem which they must overcome by learning the necessary content without receiving previous explanations.[1] While there are several interpretations of what is meant by inquiry,[2] in this study it will be considered as (ref 3, p 4)

> *[T]he intentional process of diagnosing problems, critiquing experiments and distinguishing alternatives, planning investigations, researching conjectures, searching for information, constructing models, debating with peers, and forming coherent arguments.*

As such, the differences between IBSE methods lie in the degree of challenge that students have,[1] and the level of scaffolding provided by the teacher to guide them.[4]

At an international level there is a general consensus that the IBSE approach is successful in overcoming the problems of lack of interest and motivation in the subject of science and its learning.[2,5,6] This is supported by extensive research which has shown that if adequate scaffolding is provided,[7] the IBSE approach can allow students to enhance and retain their conceptual understanding.[8] Furthermore, it can help them to develop their reasoning and problem-solving skills,[9] articulate their thinking, and reflect on their learning.[4]

However, in reality the use of inquiry-based methodologies has been somewhat limited at primary and high school levels. This could be due to a number of beliefs, such as the thought that they require a lot of time in the classroom, the presumed burden they place on the teacher, and the supposed lack of adequate materials.[10,11] Moreover, from both pedagogical and psychological perspectives some authors are skeptical about their effectiveness,[12] although this could result from an incorrect association with "minimally guided instruction" or discovery learning.[4]

To overcome these issues and promote wider use of IBSE methods, it is necessary to develop teacher training initiatives which incorporate them for future primary[13,14] and secondary[15−17] school teachers. This should be done for the following reasons:

- Teachers are the principal agents in terms of updating scientific education.[5] While it is necessary that schools promote *being innovative*[15] and create a collaborative educational culture,[18] it is also indispensable that individual teachers are encouraged to be creative through their initial training.

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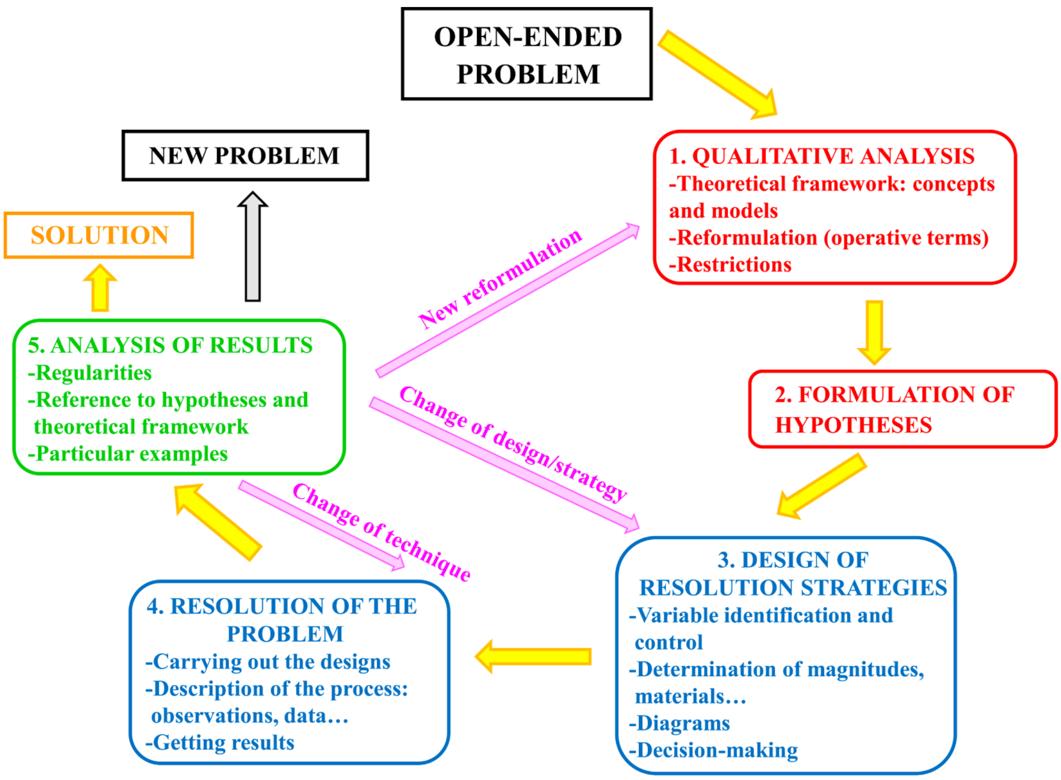

Figure 1. Stages and characteristics of the MPSI as a cyclic process.

- Future teachers should personally experience IBSE methods and reflect on their nature, by taking part in inquiry processes themselves and receiving feedback from experts. Moreover, the practical phases of these programs provide excellent opportunities to implement these methodologies.[15,17]

There has already been some research done in the area of IBSE with preservice secondary science teachers. In one study, which is quite similar to our own research, a project-based distance learning approach was taken to analyze a series of videos about different teaching practices.[16] In our case, stemming from a previous project about primary teacher training,[14] we propose a face-to-face program based on the resolution of *professional problems*. The way in which our proposal differs from previous ones[13,15−17] is that in order to design classroom activities we focus specifically on the use of teaching units based on *sequences of open-ended problems*. In addition, as it will be explained in the paper, we consider the necessity of taking the role of secondary school students, and for that purpose preservice teachers are asked to solve an inquiry-based sequence of chemistry problems.

The context of this research is the physics and chemistry specialization of the Spanish one-year Master's in Secondary Education (MSE). This is a necessary requirement for working as a teacher in secondary education (ages 12−18), whose main characteristics are explained in the Supporting Information.

THEORETICAL FRAMEWORK: METHODOLOGY OF PROBLEM-SOLVING AS AN INVESTIGATION

In this paper we will look at problem-based learning (PBL) as a methodology of inquiry, with a specific focus on the methodology of problem solving as an investigation (MPSI)[19] in the context of the MSE for physics and chemistry teachers. Research on the implications of this methodology has previously been carried out on secondary school classes[8,19−22] and primary school teacher training programs[14] by our department, but this will be our first comprehensive study of its use in the Master's program. Our previous studies gave us very good results in terms of both conceptual and procedural change[8,14,21] of students and their attitudes toward science and its learning.[20,21]

The MPSI is designed to solve *authentic problems*, both experimental and theoretical, which consist of open-ended statements (without data and with various possible solutions). For this reason, the five stages of the methodology resemble the ways of working of a novice researcher in a research team[19] (see Figure 1).

An initial step in problem solving should consist of a *qualitative analysis* (stage 1), describing an appropriate theoretical framework (the implied concepts and models) and reformulating the problem in operative terms. Then students would *formulate* their *hypotheses* (stage 2), and these conjectures will orientate the whole resolution, indicating the parameters to keep in mind when analyzing the results. The next step consists of developing one or more *resolution strategies* (stage 3) to check the validity of the hypotheses and the theoretical framework. For this purpose, independent, dependent, and control variables should be identified, along with the materials and magnitudes to be considered. The next task is the *resolution of the problem* (stage 4), taking note of the observations and measurements, and verbalizing the entire process. The final step is the *analysis of results* (stage 5), with reference to the hypotheses and the initial qualitative analysis. This phase consists of testing the internal validity of the whole resolution, and as such could give rise to new questions and problems. Therefore, these stages should not be understood as

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Table 1. Comparison of Content and Assessment Criteria about Chemical Changes with an Aligned Sequence of Open-Ended Problems Considered in the Teaching Unit

Third Level (Ages 14−15) Spanish Education Curricular Requirements		
Content	Assessment Criteria	Teaching Unit: "Change and Diversity in Nature" Sequence of Open-Ended Problems: What might happen when...
Physical and chemical changes	Distinguish between physical and chemical changes by realizing simple experiments.	1. ...Two substances are placed into contact with each other?
Chemical reaction	Characterize chemical reactions as changes of some substances into others.	2. ...Water is added to a substance?
Simple stoichiometric calculations	Describe, at the molecular level, the process by which reagents are transformed into products.	3. ...A substance is heated up?
Law of conservation of mass	Deduce the law of conservation of mass and recognize reagents and products by means of simple laboratory experiments.	4. ...Electricity passes through a substance?

a linear sequence, but rather as a cyclical process which allows for successive revisions.

The fact that the MPSI gives such importance to the qualitative analysis of open-ended problems and their reformulations allows for improvement in terms of not only procedural but also conceptual skills.[23] Therefore, this methodology is advisable according to the general international consensus for the development of *scientific competencies*. Moreover, during this whole process the teacher is expected to promote verbalization as a fundamental aspect of metacognitive development, and guide the students to *learn how to learn*.

■ OBJECTIVES

This study will focus on the use of a problem-based learning (PBL) methodology in the MSE context. As such, the objectives that guided this study included the following:

1. Describe an initial teacher-training proposal for the inclusion of the MPSI in the teaching and learning of secondary school chemistry, with a specific focus on the roles of the students and the professor.
2. Analyze the level of achievement by future physics and chemistry teachers, in terms of the MPSI dimensions of scientific competencies, when solving the open-ended problem "What might happen when two substances are placed into contact with each other?" (the first of a sequence of problems).

■ METHODOLOGY

This is a descriptive and qualitative case study set in the context of educational research. The sample consisted of a class group enrolled in the MSE in the Universidad Complutense de Madrid (UCM). It was made up of 17 students (average age 28.2; 8 female and 9 male; 6 chemistry graduates, 6 physics graduates, and 5 with other degrees, mainly engineering) who submitted the written report about the considered open-ended problem within the deadline.

In order to develop the first objective of this study, we have considered the following question: How did we work with the MPSI in the chemistry education subject of the Master's program? In this paper we will specifically describe the resolution of the previously mentioned problem about chemical change.

With regard to the second objective of the research, the data was obtained from the individual reports that the MSE students wrote a week after ending the experiments, in terms of the MPSI stages (see Figure 1). In order to make the analysis easier, stages 1 and 3 were divided into the following competence dimensions (CD).

- CD1.1: Qualitative representation of the problem (theoretical framework)
- CD1.2: Reformulation of the problem
- CD3.1: Variable identification and control
- CD3.2: Decision making for the problem

For the analysis, first the problem was solved according to what was expected as a satisfactory level for the MSE. Following this, achievement levels were established in terms of the competence dimensions. A precise definition of these levels for the problem is shown in the Supporting Information, but all of them follow these rules:

- Level 0: Irrelevant answer
- Level 1: The answer lacks important information or contains important mistakes
- Level 2: Average answer that lacks some information or contains small mistakes
- Level 3: Good answer, although some information is missing
- Level 4: Very good answer

The consensus of the two researchers was required for this analysis and the subsequent coding of the reports. Finally, in order to take a wider perspective of the relative success of future teachers in terms of the aforementioned competence dimensions (CD), the average resolution level between 0 and 4 and the standard deviations were calculated for each CD, similarly to other studies.[19,21]

The results of this paper will correspond to the first open-ended problem of a sequence, with the intention of shedding light on the future teachers' initial difficulties related to thinking scientifically.

■ OBJECTIVE 1: HOW DID WE WORK WITH THE MPSI IN THE CHEMISTRY EDUCATION SUBJECT OF THE MASTER'S PROGRAM?

The chemistry education subject in which the study was done consists of project-based learning about a variety of professional problems such as content selection, design of learning activities, and assessment of the teaching and learning process. The students constructed their knowledge collaboratively under the supervision of the professor and, for their assessments, designed a teaching unit that was made up of all the aspects they had developed during the course.

For this paper we considered the following professional problem: "What activities should be included in a teaching unit, and how can they be designed?" During its development the MSE students were introduced to the MPSI through a teaching

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unit devised by the professor called "Change and Diversity in Nature". This proposal was based on a sequence of open-ended problems to tackle chemical reactions, in accordance with Spanish curricular requirements for students at ages 14−15, as indicated in Table 1. In this way it is considered that the future teachers' learning, both of and through the MPSI, and their subsequent reflections form an essential basis on which to facilitate the learning of their future secondary school students.

How Did We Introduce the Problem "What Might Happen When Two Substances Are Placed into Contact with Each Other?"

First of all, it was necessary to familiarize the future teachers with the MPSI. In order to do this, preservice teachers had to start solving the open-ended problem "Which piece of paper absorbs more?" without any scaffolding.[22] Their answers showed that they concentrated their efforts on the resolution strategies (although they did not consider some important control variables, either explicitly or implicitly), and they did not qualitatively analyze the problem. Following this, the professor presented the educational justification of the MPSI, and later the methodology was used for the resolution of the previous problem about pieces of paper. During this process, the professor provided an instruction sheet, which is shown in the Supporting Information.

The MSE students were then asked to develop the first three stages of the MPSI (the research planning) of the open-ended problem analyzed in this paper for homework. Then, in the next class session of 90 min they did practical laboratory experiments to solve the problem, in collaborative groups that were established at the beginning of the course by the professor. Each group contained at least one physics graduate and one chemistry graduate. Finally, each preservice teacher had to submit an individual report communicating the five stages of problem solving according to the MPSI within a week.

For the practical experimental work two solids of a similar appearance (white and crystalline, both water-soluble) identified as "A" and "B" were provided. Taking this information into account, the groups had to revise and finalize their resolution proposals.[24] In Figure 2 the minimum required materials are shown. These materials are basic, inexpensive laboratory equipment, although the MSE students were freely able to use other resources from the chemistry laboratory of the UCM Facultad de Educación.

Figure 2. Proposal of minimum materials to solve the open-ended problem.

The proposed substances were small quantities of lead(II) nitrate, $Pb(NO_3)_2$, and potassium iodide, KI. This chemical reaction is very common at both secondary school and university levels because of its educational value, as it can be easily analyzed in terms of color and solubility. However, the activity we implemented was presented in a different way, as an open-ended problem that allowed the MSE students to work with a variety of chemical concepts and procedures (see a complete guide of the activity in the Supporting Information, where some hazards are also described). In the following section we will describe our way to work in order to facilitate the resolution of the problem.

How Was the Problem Solved? On the Roles of the MSE Students and the Professor

The process of teaching and learning through the MPSI should take place in cooperative, learner-centered groups, with the assistance of the teacher in order to help them to construct knowledge. Therefore, working with this IBSE-method implies changing the traditional roles of students and teachers during problem-solving.[18] As such, during this process in the MSE, the professor used the strategy of posing questions to the students in order to orientate the process.[25]

At the beginning of the practical stage of the problem a majority of the MSE students proposed producing water solutions of the substances, which is the "classical" way of promoting chemical reactions. In these cases, the professor was able to redirect the students' proposals using questions such as "If you use water, wouldn't you be placing three substances into contact with each other? Is there an alternative way...?" In reality, one of the proposed substances (KI) is hygroscopic, so there is no need to make solutions of the substances. Therefore, this activity encourages reflection about the different ways in which contact between two substances could take place in nature.

After this initial reflection, several groups of MSE students started to place the two substances in contact in solid states, but in different ways. Some of them added small quantities of "A" and "B" to a test tube, and having not perceived any visual change said "nothing happened". These kinds of statements are typical when dealing with the topics of physical and chemical changes, as it seems that "something happens" only when there is an emission of gas, an explosion, a change in color, and so on. For this reason, these facts bring us to question the use of only "visually attractive activities" in chemistry, as they could mask the true extent of these changes.

However, other preservice teachers who lightly shook the test tube did start to notice a change in color from white to yellow, although they were unable to do so as clearly as those who chose to use a mortar (see Figure 3). Consequently, when comparing their procedures with each other, the groups were able to reflect on the influence of the contact surface or the length of time that "A" and "B" are in contact.

At that moment, the idea that a chemical reaction had taken place had already emerged. This was an appropriate time for the professor to pose questions such as "Is a change in color enough to determine the type of change that has occurred? Does this change necessarily imply a chemical reaction?" That is, the preservice teachers were indirectly suggested to test this hypothesis in a practical way.

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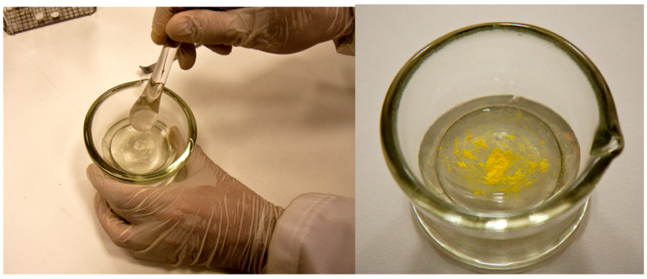

Figure 3. Change in color of the sample after using a mortar, from white to yellow.

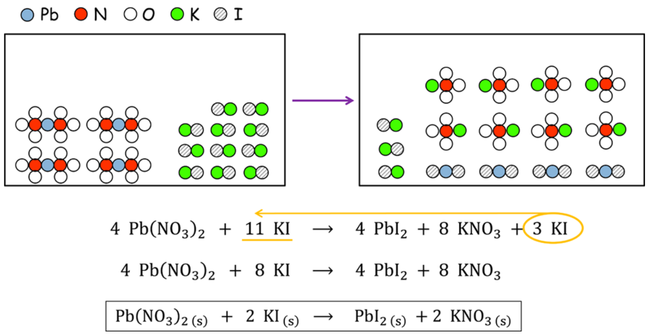

Figure 4. Obtaining a balanced chemical equation starting from a particular microscopic situation, considering the law of conservation of mass and the states of matter. (In accordance with the kinetic molecular theory, solid substances are drawn by following some regularity patterns, although this is not done in a three-dimensional way.)

A possible procedure to determine whether a chemical reaction has occurred is to analyze changes in characteristic properties, both physical (e.g., melting points or solubility) and chemical (e.g., thermal decompositions), taking into account the available resources in school laboratories. As a result of group reflection, the property of solubility was proposed as a criterion to determine the type of change (and it was concluded that the change was effectively chemical).

After these experiments, the future teachers were advised of the need to characterize what had taken place using symbolic representations. Some of their proposals included:

$$A_{(s)} + B_{(s)} \rightarrow C_{(s)}$$

$$A_{(s)} + B_{(s)} \rightarrow C_{(s)} + D_{(s)}$$

This was a good opportunity to tackle questions such as "Would you end up with just 'C', or just 'C' and 'D'?" The purpose of this is to activate preservice teachers' knowledge about limiting and excess reagents, and favor its application to the activity. In this way new proposals were made:

$$A_{(s)} + B_{(s)} \rightarrow C_{(s)} + A_{(s)} \text{ or } B_{(s)}$$

$$A_{(s)} + B_{(s)} \rightarrow C_{(s)} + D_{(s)} + A_{(s)} \text{ or } B_{(s)}$$

As such, some MSE students stated, "The second proposals are more likely to have happened, as we haven't worked with stoichiometric proportions." At this point, preservice teachers were able to design strategies to practically determine the limiting and excess reagents, characterize the reagents and products, and other relevant aspects that are included in the guide for the activity (see Supporting Information).

Here we need to point out that, in the Spanish school curriculum for students aged 16 and under, chemical reaction concept constructions are limited to reactions completely displaced toward the products. Consequently, this fact implies a didactic transposition which assumes chemical changes as irreversible.

In terms of the analysis of results, microscopic representations of the process were promoted, an aspect which has been explored in other research contributions to this *Journal*.[26−28] Our proposal (see Figure 4) starts from particular microscopic situations represented according to Dalton's model, and all these situations lead to a unique chemical equation with stoichiometric proportions. Therefore, instead of being simply an algebraic procedure, this procedure for balancing chemical equations focuses on its chemical interpretation.

As a final reflection on the whole learning experience, we believe that the fact that preservice teachers were able to observe the "real" role of the professor as a guide in the MPSI will prompt reflection on the role which they should adopt in their future classes.

OBJECTIVE 2: RESULTS FROM PRESERVICE TEACHERS' WRITTEN PRODUCTIONS

We studied how the described group of preservice teachers wrote their reports about the previously explained open-ended problem. The frequencies of the achievement levels and their mean values for each competence dimension are shown in Table 2.

Table 2. Distribution of Achievement Level Frequencies, Mean Values, and Standard Deviations

Competence Dimension Measured		Student Response (n = 17) Frequencies at Each Level[a]					Scores[b] (n = 17)	
		L0	L1	L2	L3	L4	Mean	SD
CD1.1	Qualitative representation	0	7	3	5	2	2.12	1.08
CD1.2	Reformulation of the problem	3	2	3	4	5	2.35	1.45
CD2	Formulation of hypotheses	0	1	4	4	8	3.12	0.96
CD3.1	Variable identification and control	1	7	2	4	3	2.06	1.26
CD3.2	Decision making for the problem	1	4	7	4	1	2.00	0.97
CD4	Resolution of the problem	0	2	6	7	2	2.53	0.85
CD5	Analysis of results	0	5	6	6	0	2.06	0.80

[a]The levels range from 0 (irrelevant answer) to 4 (very good answer). [b]Scores were determined by assigning an achievement level to each answer using a rubric (see the Supporting Information); thus, scores range from 0 to 4.

Concerning the formulation of hypotheses (CD2), the results obtained were very good and 47% of the preservice teachers wrote responses classified at level 4, such as "When placing two substances in contact they will react, causing a chemical change and producing new substances. It will be an irreversible change." (Student 17.) In other similar studies (although not with Master's students), the results in CD2 seem to very much depend on the context of the problem, being

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better for the cases in which the statements are more relevant to the students.[19,21]

With regard to the resolution of the problem (CD4), judging by the high achievement levels, it seems that future teachers were more used to describing experimental procedures, observations, and data (objectives of this step) rather than analyzing them, or planning the resolution strategy by themselves. In fact, the results in the third step of the MPSI—variable identification and control (CD3.1) and decision making for the problem (CD3.2)—were the worst in this study (see Table 2). However, the mean achievement levels were not lower than 2. In order to provide a clearer picture of future teachers' responses, Table 3 shows some examples of different achievement levels for CD3.1. The MSE students who obtained a level 2 in this competence dimension correctly identified the dependent variable, while those with level 3 were also able to identify the independent variable. The students who achieved level 4 additionally managed to include some control variables.

Table 3. Classification of Answers for "Variable Identification and Control", CD 3.1, by Achievement Level

Level[a,b]	Examples of Student Answers (n = 17) Assigned to the Respective Achievement Levels
1	Dependent variable: chemical transformations, degree of mixing, state of aggregation of matter
	Independent variable: reagents' composition
	Control variables: atmospheric temperature and pressure
	[Student 16; Representative of 41%]
2	Dependent variable: reactivity of A with B (they react or do not react)
	Independent variable: temperature
	Control variable: atmospheric pressure
	[Student 13; Representative of 12%]
3	Independent variable: type of substances (their nature and properties
	Dependent variable: type of reaction that happens (chemical reaction)
	[Student 14; Representative of 24%]
4	Dependent variable: physical change (hypothesis 1) or chemical change (hypothesis 2)
	Independent variable: type of substances
	Control variable: temperature
	[Student 12; Representative of 18%]

[a]Level 1: The answer contains important mistakes. Level 2: Average answer that contains some mistakes. Level 3: Good answer, although some information is missing. Level 4: Very good answer. [b]Responses were determined to be at level 0 (irrelevant answer) for 6% of students.

As for the steps of the qualitative analysis of the problem, the results in its reformulation (CD1.2) were better than those of the qualitative representation (theoretical framework, CD1.1), as can be seen in Table 2. Future teachers were more successful in providing an operative statement for the problem than in developing a theoretical framework that focused on physical and chemical changes. An example of CD1.2 from each extreme of the scale would be as follows.

- Level 1: "'Mix' two solid substances in order to deduce what happens." (Student 4, representative of 12%)
- Level 4: "We will check if the two substances that are placed in contact with each other cause a chemical reaction (irreversible process) or if simply a physical change occurs (reversible process)." (Student 2, representative of 29%)

Moreover, in Table 4 the explanations of the chemical contents in the theoretical frameworks (CD1.1) of four future teachers are shown; they were classified between levels 1 and 4. It can be noted that what marks the difference between the higher and lower levels is the development of aspects associated with chemical change (with its three levels of representation), which is the key to the problem. In addition, those who achieved the highest level were able to explain what comprises contact between two substances.

Table 4. Chemical Content Some MSE Students Described in the "Qualitative Representation of the Problem", CD 1.1, by Achievement Level

Chemical Content Concepts	Student 10 Level 1[a,b]	Student 8 Level 2[a,b]	Student 2 Level 3[a,b]	Student 12 Level 4[a,b]
Matter	+	+	+	
Chemical substance	+	+	+	+
Element		+	+	+
Compound		+	+	+
Properties of substances (physical and chemical)		+	+	+
Solubility as a property		+	+	+
Physical change		+	+	+
Examples of physical changes				+
Chemical change (reaction)		+	+	+
Reagents and products			+	+
Change in macroscopic properties		+	+	+
Microscopic view of a reaction			+	
Symbolic representation (chemical equation)				+
Examples of chemical reactions				+
Reversibility/irreversibility of changes		+	+	+
Law of conservation of mass			+	+
Dalton's model	+			+
Contact between substances				+
Possibilities for contact depending on the state of matter				+

[a]Level 1: The answer lacks descriptions of most of the concepts related to the problem. Level 2: Average answer that lacks some explanations. Level 3: Good answer, although some information is missing. Level 4: Very good answer. [b]The empty spaces in the columns indicate some concepts that were not explained by the MSE students.

Finally, concerning the analysis of results (CD5), although six of the preservice teachers obtained a level 3 here (35%), none of them achieved level 4, which would include a thorough explanation with reference to the theoretical framework and hypotheses described. Table 5 shows some answers at different achievement levels. We can observe that Student 11 (level 1) shows confusion with the analysis, probably because of the openness of the problem. The example of a level 2 answer makes reference to the hypothesis, but does not include experimental evidence to support the analysis. On the other hand, Student 5 (level 3) provides practical information in the

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Table 5. Classification of Answers for "Analysis of Results", CD 5, by Achievement Level

Level[a]	Examples of Student Answers (n = 17) Assigned to the Respective Achievement Levels
1	It is very difficult to get quantitative results without having any starting data. However, we have been able to see a chemical reaction in this process. We could not also determine the stoichiometry of the reaction [Student 11; Representative of 29%]
2	We can conclude that hypothesis 1 is correct due to the chemical reaction that occurred when placing the two substances in contact. We obtained a new substance with different properties. This was an irreversible reaction. [Student 3; Representative of 35%]
3	In this activity, the two substances that were placed in contact gave rise to a chemical reaction. In particular, by means of the design proposed for testing hypothesis 1, we clearly observed how the two compounds A and B reacted after grinding them. We obtained a yellow compound C, totally different from the initial ones. Substance C was water insoluble, whereas A and B were soluble. It would have been interesting to see what happens when placing water solutions of A and B in contact. [Student 5; Representative of 35%]

[a]Level 1: The answer lacks important information or contains important mistakes. Level 2: Average answer that lacks some explanations. Level 3: Good answer, although some information is missing.

explanation, but still lacks symbolic and microscopic representations of the process.

CONCLUSIONS

In this article we have presented a proposal for preservice science teacher training within the Spanish MSE program. In addition, we have provided detailed guidelines to implement an open-ended problem about chemical change, which could also be useful for secondary education levels.

Contrary to what people may think, inquiry-based methods such as the MPSI require greater teacher involvement than in transmissive methodologies.[25] Moreover, they demand a revision of the traditional roles of both teachers and students in the learning process.[18] Therefore, in the *first part* of the paper we explained the necessity of providing opportunities to future teachers to participate in inquiry processes themselves. In this way, preservice teachers can properly reflect on the characteristics of these methodologies and their benefits for science education.

It is important to reflect that despite the considerable degree of openness of the initial problems, the scaffolding provided by the teacher is fundamental to the MPSI. This feature helps to overcome possible student resistance[1] (because of their need to become responsible for their own learning) and allows for the appropriate reformulation of the initial statements. Additionally, good design and planning processes are essential in order to promote effective learning.[29] As such, possible alternative conceptions and student difficulties must be taken into account. For these reasons, we believe that directly experiencing how a qualified teacher provides scaffolding is especially valuable for the challenge of including IBSE methods in their future secondary school teaching.

With regard to the second objective of this study, the results we obtained from their written reports of the first open-ended problem of the sequence indicate that at this stage future teachers did better at describing the resolution of the problem (CD4) and formulating hypotheses (CD2). However, they had more difficulty identifying variables (CD3.1), which is perhaps because they are less frequently analyzed in chemistry. They also had issues making decisions to solve the problem (CD3.2) and critically analyzing the results (CD5).

These results suggest that future teachers may find it easier to carry out experimental work in a guided way (following laboratory guide notes), possibly because of the way in which they have learned in their previous studies.[5] Moreover, the results point out some deficiencies in preservice teachers related to thinking scientifically, and bring us to rethink the way in which practical activities are developed at university levels.

It should be noted that in this paper we focused on only the first stage of the learning proposal. Consequently, we have not included the corrections and group feedback of the MSE students,[30] nor the resolution of the other problems of the sequence. In accordance with results we have previously obtained in the context of preservice primary teacher training,[14] we would expect that these aspects of the learning process would facilitate improvement of the scientific competencies included in the MPSI. In addition, more examples covering content at different school levels should be developed, and future teachers should be encouraged to design other open-ended problems with feasible solutions (providing the corresponding hypotheses and resolution strategies).

On the other hand, at present we are carrying out research in some groups of physics and chemistry preservice teachers who have worked with the MPSI in their MSE program, in terms of their views on this methodology. In general, they emphasize the usefulness of the MPSI for encouraging secondary school students to become familiar with scientific procedures, and developing positive attitudes toward science as a whole. However, they also highlight the difficulty involved in applying the MPSI. Moreover, it is noteworthy that we have found a statistically significant correlation between future teachers' traditional or constructivist beliefs and their opinions on the MPSI.

For all of the above reasons, in the future it is recommended to continue this line of research, together with the analysis of the future teachers' improvement as they progress with the learning process. Equally, we think that it would be useful to carry out similar studies, as it has been suggested that the reactions to inquiry-based methodologies strongly depend on the context.[31] In addition, as has been done in some other studies,[15] it would be especially valuable to administer this type of research during the practical teaching phase of teacher training programs.

Even more so, it would be very worthwhile to observe how these students teach when they finally begin working in secondary schools. To what extent do they use inquiry-based methods? And how does this improve the quality of science education?

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available on the ACS Publications website at DOI: 10.1021/acs.jchemed.5b01037.

Information about the Spanish Master's in Secondary Education, MPSI Instruction Sheet, detailed guide and hazards, and rubrics (PDF, DOCX)

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AUTHOR INFORMATION

Corresponding Author

*E-mail: mtzaznar@ucm.es.

Notes

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