Educación Química

Qualitative polymer analysis lab through inquiry-based

Actividades de indagación en análisis de polímeros

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Abstract

The present study has two main objectives: to acknowledge student's arguments through the discussion of plastics use in our society; and how students engage in scientific-oriented activity plan and implement a protocol to identify qualitatively different polymers present in a bottle of water (on the bottle itself and on its cap and label), therefore formulating explanations based on evidence. Taking this into account, inquiry-based activity was developed bearing in mind the inclusion of role-playing debate approach and laboratory work. The activity was implemented with 20 students from school year 12, attending Chemistry classes. Data was collected through teacher's observation and students' answers and records. Students planned and performed the laboratory activity with a considerable degree of autonomy; however, the process of collecting and registering information was not always precise and complete. Despite some identification difficulties of the plastic present on the bottle label, perhaps due to some lack of procedural accuracy, the other two polymers present in the bottle were identified. Moreover, students formulated scientific explanations based on experimental evidence. Encouraging pupils hypothesis elaboration, and questions formulation engaging in a classroom debate, using evidence from the real world is essential and an ongoing challenge for chemistry learning through inquiry-based approach.

Keywords

Chemistry teaching; High School; Inquiry-based; Qualitative polymer analysis lab.

Resumen

Este estudio tiene dos objetivos principales: conocer los argumentos que los estudiantes presentan al discutir el uso de plásticos; y cómo participan estos en un plan de actividades de orientación científica e implementan un protocolo para identificar polímeros cualitativamente diferentes y presentes en una botella de agua, su tapa y etiqueta, por lo tanto formulan explicaciones basadas en evidencia. Así, la actividad basada en indagación se desarrolló teniendo en cuenta la inclusión del enfoque de debate de juego de rol y el trabajo de laboratorio. La actividad se implementó con 20 estudiantes del 12 º año escolar, que asistieron a clases de Química. Los datos fueron recolectados a través de la observación directa y de las respuestas y registros de los estudiantes. Los estudiantes planificaron y realizaron la actividad de laboratorio con un considerable grado de autonomía. El proceso de recopilación y registro de información no siempre fue preciso y completo. Se identificaron los polímeros a pesar de algunas dificultades en la tarea. Alentar las acciones, formulaciones y preguntas de los alumnos, y debatirlas, utilizando evidencia del mundo real para abordarlas, es esencial y un desafío continuo para el aprendizaje de la química a través del enfoque basado en la indagación.

Palabras clave

Enseñanza de la química; Educación secundaria; Indagación; Laboratorio de análisis cualitativo de polímeros.

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Introduction

Polymers and their relevance to society

People have always used polymers, especially those that come from plants and animals, such as wood, rubber, cotton, wool, cellulose, and silk. Other polymers are fundamental for biological processes in plants and animals, such as proteins, enzymes, starch, and cellulose. According to IUPAC, polymers are macromolecules which have high relative molecular mass and "the structure of which essentially comprises the multiple repetition of units derived, actually or conceptually, from molecules of low relative molecular mass" (McNaught & Wilkinson, 1997, p. 2289). And with the contribution of chemistry, alternative materials were found – for instance, new synthetic polymers with adequate properties for daily use in medicine, cosmetics, pharmaceutics, packaging, etc. This strong demand for new polymers was guided by factors such as their durability, tensile strength or resistance to degradation.

In general, plastics and fibers are mixtures of several substances whose main constituent is a polymer. However, there is a vast set of substances added to plastics that grant particular properties to them. Therefore, plastics are inexpensive, long-lasting and resistant, with a low density, flexible or rigid, easily moldable and colored in several designs, and efficient electrical and thermal isolators. These properties, together with polymers' low production cost, make them so widely used (Brinson and Brinson, 2008). As a consequence, they produce large quantities of non-degradable urban waste, which leads to an environmental problem. Nevertheless, this disadvantage has been the driving factor in boosting the research on biodegradable polymers, whether natural or synthetic (Williams and Hillmyer, 2008; Garrison *et al.*, 2016).

Polymers in a chemistry curriculum in school year 12

The Chemistry subject in school year 12, as a pre-university course, should present a contemporary vision over relevant aspects in the knowledge of chemistry – defining different scientific views of interpreting the world, so as to proceed in the direction of a more profound interpretation in a higher education level.

Cersonsky *et al.* (2017) affirm that only 12 states of the USA address polymer-related concepts in pre-university science curricula and that "California is the only state that introduces polymers before high school". This could be an indicator of the low representation of polymers in Chemistry's curricula, and so an effort should be done to highlight polymers' chemistry taught to high school students.

In 2014, in Portugal, new standards were implemented for the school year 12 Chemistry curriculum (Fiolhais *et al.*, 2014). Thus, the curriculum is organized in three domains and its respective subdomains, as presented in Table 1. Regarding this article's objective, we highlight the domain "Plastic, glass and new materials", as well as its three subdomains (Martins, 2004; Fiolhais *et al.*, 2014): 1) "Plastic and polymeric materials" – which aims to portray polymers as a class of materials consisting of macromolecules, distinguishing natural and synthetic polymers; 2) "Synthetic polymers and the industry of polymers" – where students should be able to understand how to obtain synthetic polymers and recognize that their structure determines their properties; 3) "New materials" – aiming for the recognition of some biomaterials and correspondent applications, as well as the advantages and limitations when using sustainable materials. Besides that, it is also important to refer that previous to this course, Organic Chemistry has a residual presence in Portuguese Chemistry curricula. Only nomenclature of alkanes and their derivatives and introductory concepts about functional groups were taught previously in year 12. This Chemistry course for school year 12 has a weekly workload of two classes during the school year, in a total of about one hundred classes, of 90 minutes each. The course program recommends that one of the weekly sessions is presented as a practical laboratory lesson, in an adequately equipped laboratory.

Table 1. Domains and subdomains in the Chemistry Curriculum for year 12

Chemistry Curriculum for year 12	
Domains	**Subdomains**
Metals and alloys	Structure and properties of metals
	Degradation of metals
	Metals, environment and life
Fossil fuels and environment	Fossil fuels: coal, crude oil and natural gas
	Where does fossil fuel energy come from
Plastic, glass and new materials	Plastic and polymeric materials
	Synthetic polymers and the industry of polymers
	New materials

Teaching polymer concepts through inquiry-based approach

In Portugal, the Chemistry program for school year 12 has a national scope and allows for "the free choice of tasks, exploring strategies and teaching methodologies according to the students' interests and development, an aspect that may be considered as a flexibility method, aiming at a better adjustment to students' interests and a motivational trigger for the study of Chemistry" (Martins, 2004). Considering this idea of flexibility and adjustment of pedagogic strategies that the Portuguese program allows, teaching polymer concepts in school year 12 Chemistry courses through inquiry-based approach could be an effective possibility (Mc Ilrath *et al.*, 2012).

According to Abd-El-Khalick *et al.* (2004), 'Inquiry' has become a perennial and central term in the rhetoric of past and present science education reforms. "Students' profile on leaving compulsory education" (Martins, 2017) and "Essential Learnings – Chemistry, year 12" (Direção Geral de Educação, 2018) are frameworks developed by the Portuguese Ministry of Education that also meets National Research Council guidelines (NRC, 2020; NRC, 2012). Based on that, many researchers (Avraamidou and Zembal-Saul, 2010; Cuevas *et al.*, 2005; Howes *et al.*, 2009; Liang and Richardson, 2009; Smolleck *et al.*, 2006) mention six essential features of classroom inquiry that apply across grade levels: i) learners address scientifically oriented questions; ii) they plan and carry out investigations to gather evidence; iii) they give priority to evidence in responding to questions; iv) they formulate explanations for evidence; v) they connect explanations to scientific knowledge; vi) and they communicate and justify explanations. NRC describes inquiry as "a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to observe the existing evidence; planning investigations; reviewing the existing evidence in light of experimental evidence; using tools to gather, analyze and interpret data; proposing answers, explanations and predictions; and communicating results" (NRC, 2012) Several studies support the effectiveness of inquiry-based as an instructional approach. Alfieri *et al.* (2011), for example, performed a meta-analysis comparing inquiry to other forms of instruction, such as direct instruction or unassisted discovery, and found that inquiry teaching

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resulted in better learning. A meta-analysis by Furtak *et al.* (2012) incorporated studies using a broad range of terms to describe inquiry-based learning (e.g., mastery learning, constructivist teaching); they reported an overall mean effect size of .50 in favor of the inquiry approach over traditional instruction. Some research has shown favorable results when applying an inquiry-based approach to the teaching of polymers, as one can see in Noiwong and Phinyocheep (2012) who applied a guided-inquiry laboratory exercise on tensile properties of composite polymers based on natural rubber to 94 secondary students in their Chemistry courses. Mc Ilrath, Robertson and Kuchta (2012) also had encouraging results when they developed and implemented a lab activity that "intended to provide a new route to introduce students to polymer science through a hands-on, inquiry-based activity in which students synthesize a polymer and investigate its mechanical properties".

Based on the framework proposed by Pedaste *et al.* (2015), it is recommended that the inquiry-based learning process should begin with an orientation phase, where students not only get an idea about the research topic but are also introduced to the problem to be solved. In the following step, students are supposed to identify the key concept to be studied in the inquiry-based learning process, for which they have different possibilities: through a hypothesis-driven approach or a question-driven approach. Inquiry-based learning begins with orientation, flows from conceptualization to investigation, and usually ends with the conclusion phase. The discussion phase (which includes communication and reflection) is potentially present at all points during inquiry-based learning and connects all the other phases, because it can occur at any time during (discussion in-action) or after inquiry-based learning when looking back (discussion on-action) (Pedaste *et al.* 2015).

In this article, we present an inquiry-based activity in which part of the orientation and discussion phases were implemented through a role-playing strategy. According to King and Janis (1956), role-playing can exert a marked influence on the individual's private opinion. Besides, the clear verbalization induced by role-playing tends to increase the effectiveness of a persuasive communication. Many examples of role-playing use in science education were found in literature (Cook, 2014; Freire *et al.*, 2016). This strategy helps students to "expand the diversity of arguments presented and to make a more direct link to real-world discourse" (Smythe and Higgins, 2007) allowing them to develop communication skills and understand the importance and relevance of chemistry within our society. The implemented inquiry-based activity was named "Plastics inside and outside of water" and it was used in order to introduce the subdomain "Plastic and polymeric materials" of the school year 12 of the Portuguese Chemistry curriculum. The activity was divided in two parts: i) a role-playing debate – in which the idea was to increase the students' awareness related with the fact that the development and the large scale production of plastics promoted a paradigm shift regarding the use of these materials, which, being highly promising, led to an increase in the total plastics mass present in the countries' urban solid wastes (Geyer *et al.*, 2017) – and (ii) a laboratory component of identification of plastics, based on a simplified scheme for plastics identification.

Centered on that inquiry-based activity, we tried to answer the following questions:

- RQ1. What types of arguments do students present in favor and against the use of plastics in the current society?
- RQ2. How students engage in a scientific-oriented activity, which involves planning and implementing a simplified scheme for plastics identification, and how they formulate explanations based on evidence?

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Methods

Participants and Setting

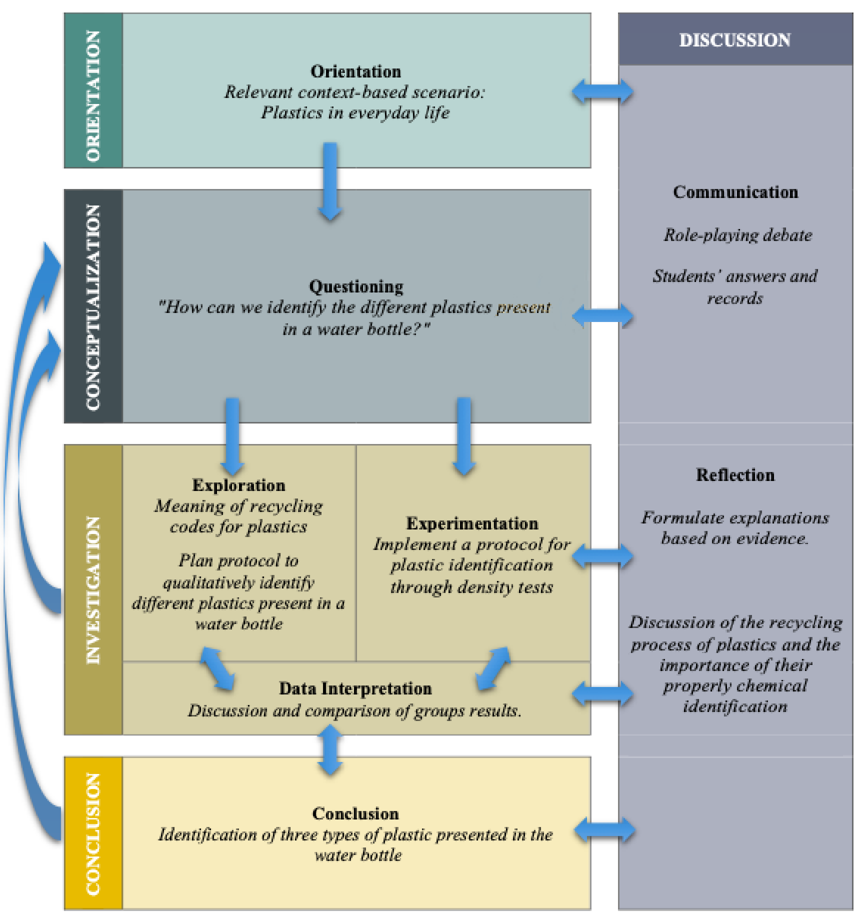
This study involved 20 students from school year 12, (13 females and 7 males, with ages ranging from 17 to 18 years old), with pre-university background in science and technology, and three Chemistry teachers – who actively planned, developed and implemented the inquiry-based activity.

The inquiry-based activity was a completely new approach for students since they never had done similar activities before. The interaction with the students took place during two Chemistry classes: one, 45 minutes long (role-playing debate), and another, 90 minutes long (research and laboratory work).

Procedure and materials

Based on the framework proposed by Pedaste *et al.* (2015) the inquiry-based activity, named "Plastics inside and outside of water" (see Supplementary Material), was created and falls into two parts: a role-playing debate and laboratory work. In order to make science education relevant to the students, the activity was integrated in a relevant context-based scenario, bridging the gap between learning in school and everyday life (Gilbert, 2016; Stuckey *et al.*, 2013). Figure 1 presents Pedaste's *et al.*(2015) framework adaptation named "Plastics inside and outside water" inquiry-based activity. The first part is an orientation phase, where students not only get an idea about the topic to be investigated but are also introduced to the general problem to be discussed. The discussion phase (which includes communication and reflection) is also present.

Figure 1. Pedaste's *et al.* (2015) framework adaptation for "Plastics inside and outside water" inquire-based activity



A set of news from online magazines and newspapers were presented to students with headings such as: "Plastic hands or parts for airplanes, the future is there, with 3D printing" and "What if biodegradable plastics are, after all, a huge lie?". This first part of the inquiry-based activity was driven by a question, "Should plastics be banned, or should they be used more rationally?" and the idea was to actively involve students in a discussion, based on arguments for and against the use of plastic.

The 20 students were randomly divided into six small groups (3 to 4 students) to collect, structure and organize arguments for and against each of the positions, inspired by the news from online magazines and newspapers quotes. Then

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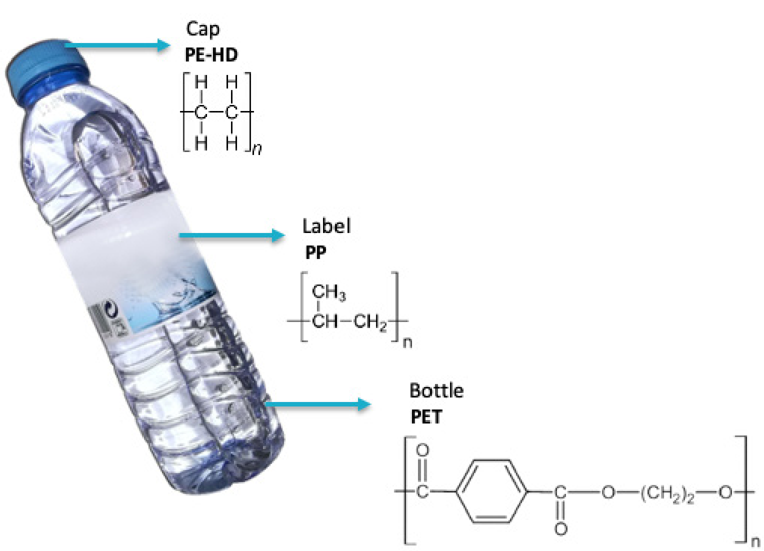
the teacher attributed the defense of the "banish plastics" position to three groups and the "use rationally" position to the other three groups. The students spontaneously joined in two large groups according to their positions. Afterwards, the six small groups elected the representatives to defend their position and organize a pros and cons role-playing debate, that was moderated by the teacher.

Following that, the second part of the inquiry-based activity called "Plastics inside and outside of water" was implemented and faced students to the following problematic scenario: […] the school canteen intends to implement a selective collection system that includes the separation of different types of plastics. In this case, it is useful to carry out an analysis of the plastics present on each part of the water bottle in order to obtain its chemical identification. Characterizing properly a plastic can be a useful contribution to promote recycling. Based on that scenario, the challenge launched to school chemistry students was: "How can we identify different plastics present in a water bottle?" Despite Portuguese schools provide drinkable water for free to its students, the purchase of bottled water is a relatively common practice in the educational community. Therefore, the idea of evoking that buying scenario was created to raise awareness about economic, social, and environmental problems related to plastic overuse and the incorrect disposal of these residues, besides the learning goals proposed to this activity. Therefore, students were invited to carry out an initial research in order to know the meaning of the existing recycling codes for plastics and discuss the recycling process of plastics and the final product quality. Once they finished that part, students could start planning a laboratory activity that would allow them to identify different plastics present in a water bottle. For this task, students needed to consider the information of the systematic scheme for plastics previously selected by the teacher. There are schemes for plastics identification which involve a sequence of simple tests, such as density tests, dissolution tests, or heating tests, that identify different types of plastics, including some of the most common ones in packaging (Hughes *et al.,* 2001; Harris and Walker, 2010; Kolb and Kolb, 1991). In our case, the scheme should be able to help the students identify, among others, PP (polypropylene), HDPE (high-density polyethylene) and PET (polyethylene ethylene terephthalate) plastics, as they are present in water bottles, as presented in Figure 2.

Figure 2. Types of raw material plastics which form a water bottle, cap and label (Chang & Goldsby, 2014).



Thus, we selected a simpler scheme involving only density tests (Hughes *et al.,* 2001) that could be used by students working in small groups, without the need for many resources and involving the use of less dangerous procedures and reagents. It is important to note that polymers' physical properties, such as density, and the chemical structure of the polymers PE-HD, PET, and PP, were unknown to students. They needed to take into account in the activity's planning. As they finished planning, the students discussed the plan with the teacher, who validated it using some guide questions, such as, "How big is the plastic sample that you are going to cut?, What is the first test that you are going to do? What test would you take next? How many tests are needed to identify PE-HD?". When the discussion with the teacher finished, students groups started to perform the activities.

According with the framework proposed by Pedaste *et al.* (2015), in these steps, students should identify the key concept to be studied and the problem to be investigated and solved in

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the inquiry-based learning process. In this phase they are moving from conceptualization to investigation and at the end they reach the conclusion phase. These phases also have several moments of discussion.

Data Analysis

Data was collected through: i) teacher's notes and observations during the students' role-playing debate and laboratory activity, and ii) students' answers and records, presented in the "Plastics inside and outside of water" activity sheet (see Supplementary Material).

Following, we present the categories of the analysis used and the activity scores.

i) Teacher's notes and observations.

The arguments of role-playing debate presented in favor of the use of plastics were analyzed considering two categories: I. Advantages of plastics (e.g. their interesting properties); II. Actions required (e.g. call for moderate use rather than non-use). In the case of arguments against the use of plastics, the following categories of argumentation were found: I. Consequences of the use (e.g. enormous environmental impact); II. Alternatives to plastics (e.g. paper and glass); III. Actions required. (e.g. increase the production of biodegradable plastics). Information about students' participation during the inquiry-based activity, initiative and autonomy carrying out the tasks and records produced during the inquiry-based activity were also obtained from the analysis of teacher's notes and observations.

ii) Students' answers and records.

A total of 15 points were assigned to students' answers and records, presented in the "Plastics inside and outside of water" the activity sheet. The points were distributed by questions according to their degree of complexity (part A: 2 points each, part B: 2, 4, 1, 2 and 2 points).

Presentation of Results

Students' arguments in favor and against the use of plastics (RQ1)

During the role-playing debate, the arguments for and against the use of plastics were discussed. Their categorization is presented in Table 2. On the one hand, students presented arguments based on features of plastics that constitute the advantages of their use – such as their durability, several designs and colors, flexible or rigid textures, diversity of application contexts, etc. – to underline the existence of these polymers and defend the continuity of its use.

To emphasize these ideas, an example of students' argument used in this discussion is highlighted: "rational and progressive reduction of the use of plastics because it is: light, flexible and easy to recycle material; important to many sectors of society; economically profitable since it has a low production cost". On the other hand, arguments were also presented that aim at some pro-activity, such as the need for actions to raise public awareness and regulate the use of plastics.

According to students, it is necessary a clear regulation of the plastics use . As an example, they presented the case of cosmetics industry, that has been sensitive to the consequences that may arise from microplastics, implemented a kind of self-regulation of their practices. We highlighted an example of students' arguments used to support these claims: "it should be immediately forbidden it's use in many sectors of activity like in cosmetics. Swabs, bags and other plastic objects should be replaced by others made by biodegradable materials".

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Categories	Arguments in favor of the use of plastics	Arguments against the use of plastics
Advantages of plastics	Very interesting properties High diversity of contexts of application	
Consequences of use		High waste rate Enormous environmental impact
Alternatives to plastics		We used to live without plastics Paper and glass as current alternatives to plastic. New materials may bring future alternatives to plastic
Actions required	Awareness campaigns for: • enhanced utility • call for moderate use rather than non-use Regulation of the use of plastics instead of prohibition	Increase the production of biodegradable plastics Review awareness campaigns given the low social impact and behavioral change they cause

Table 2. Categories of arguments presented in the role-playing debate

In the case of arguments against the use of plastics, the consequences of the use underlined by students were the enormous waste of plastics and the consequent environmental impact. Alternatives to plastics such as paper - as emphasized by students "Plastics can be replaced by other materials like paper, for example" -, developing glass and new materials have been referred as a promising future alternative to the use of plastic, such as the "replacement of plastic bottles by an algae substrate" was presented by a group of students. These alternatives were framed within a past social history when plastic was absent as a common material.

One of the actions considered necessary is the increase of the production of biodegradable plastics. The vast majority of plastics are produced from fossil fuels with monomers such as ethylene (C_2H_4) and propylene (C_3H_6) and are not biodegradable materials.

As a result, there is successive accumulation of these polymers either in their own sites, in landfills or in the environment. The only way of permanent disposal of these wastes is by thermal treatment such as combustion or pyrolysis. Therefore, the almost permanent contamination of the environment through the accumulation of plastic waste is a growing concern, although, as mentioned by the students, population have not been sensitized to this issue. It is interesting to point out that the category actions required emerged in both position cases: in favor of the use of plastics and against the use of plastics. In each case, they presented apparently different arguments; however, they have a strong overlap among them, such as the case of awareness campaigns.

Even when the class finished, the role-playing debate of arguments for and against the use of plastics continued out of the classroom space.

Students' engagement in scientific-oriented activity (RQ2)

The class was divided into six working teams. Students researched plastics online, using their smartphones and they were able to find the meaning of the recycling codes 1 through 6 for different types of plastic; the last code, 7 (see Figure in Supplementary Material), raised a greater challenge, and not all students were able to identify it as «Others». Based on the activity text, students understood and debated as a group about how the main raw material used in recycling may affect the quality of the final product – highlighting the fact that, if different plastics are collected and recycled together, the final product will have a low quality and its use will be limited. One of the groups mentioned the possibility that plastics may be contaminated, which will affect their value.

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This first research phase was important to explain the use and need of laboratory to identify plastics. A bottle of water contains at least three types of plastic (in the bottle itself, in the cap and in the label). In this activity, students had to use the available lab equipment (scissors; tweezers; two 50 ml beakers; a wash bottle with distilled water; six required solutions (for testing) and they did a systematic analysis or find the identification key – based on density tests: the plastic sample will float or sink on a given solution, depending on its density – in order to plan the identification of the three plastic samples.

Students planned the activity and once it was validated by the teacher, students began their work. The expected results were: bottle – PET (ρ = 1,39 g cm^{-3}); cap – PE-HD (ρ = 0,95-0,97 g cm^{-3}); and label – PP (ρ = 0,90-0,91 g cm^{-3}).

Within this inquiry-based activity, students were challenged to construct a table to record the results obtained, which included information on the analyzed plastic samples. It was expected that year 12 students had experience in construct tables to record the results. However, in order to help their work, some ideas and tips were given by teachers, but students did not follow regularly these instructions. For that reason, data recorded by students wasn't consistently presented (as shown in Table 3.a). However, Table 3.b demonstrate a good example of students' records, with an accurate and coherent presentation.

3.a		
Origin	**Color**	**Recycling codes**
Bottle	Green	1 - PET
Cap	White	2 – PE-HD
Label	White	5 – PP

3.b				
Origin	**Color**	**Ethanol 76,8 % ρ = 0,868 g cm^{-3}**	**Ethanol 57,9 % ρ = 0,914 g cm^{-3}**	**Ethanol 41,3 % ρ = 0,945 g cm^{-3}**
Bottle	Green	Sinks	Sinks	Sinks
Cap	White	Sinks	Sinks	Sinks
Label	White	Floats	____	____
Water ρ = 1,00 g cm^{-3}	**Sodium chloride 12% solution ρ = 1,09 g cm^{-3}**	**Sucrose 54% solution ρ = 1,25 g cm^{-3}**	**Potassium carbonate 45% solution ρ = 1,48 g cm^{-3}**	**Recycling codes**
Sinks	Sinks	Sinks	Floats	PET
Floats	____	____	____	PE-HD
____	____	____	____	PP

Table 3. Example of a record table poorly built (a) and an example of record table well built by students (b)

Having correctly identified the type of plastic in the bottle and cap, most of the students affirmed that the results of the bottle label identification (PMP) (ρ = 0,868 g cm^{-3}) didn't match the true material (PP). Only a minority of students reflected more deeply on the analysis of these results, concluding that the misidentification of the label was explained by the ethanol solution 76,8 % (V/V), as it didn't have the correct concentration for the plastic to sink. The solution had been previously tested by teachers. Nevertheless, since it was stored in a large jar, the vaporization inside probably altered its composition. Some groups didn't obtain the expected results and

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were invited to repeat their analysis. The different results were probably caused by a deficient immersion of the plastic, failing to eliminate the superficial tension. The plastic may also have been poorly cut, causing defects where air might have accumulated in small bubbles. A reflection from the students on the activity would have been helpful to understand the causes for the divergent results.

For a quantitative overview of the students' performance, Figure 3 represents the scores for their answers and records, presented in the activity sheet. Part A concerned research and initial debate on the different types of plastics and how the use of recycled plastics produce new raw materials dictates the final product's quality (A.1 e A.2). In total, 20 answers from students scored accurately these questions, and most of them had a maximum score.

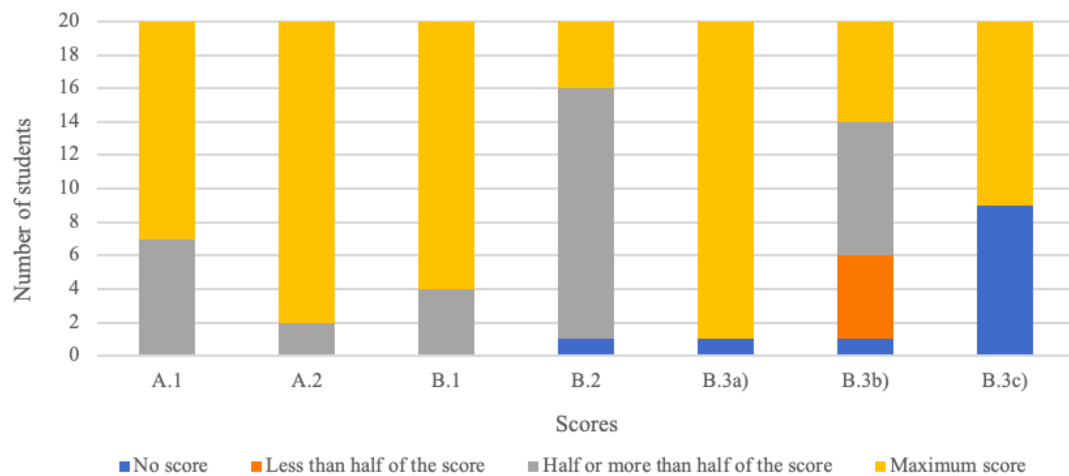

Figure 3. Students answers assessment in part A and B of the inquiry-based activity “Plastics inside and outside of water”

Part B was focused on the problem's resolution in the laboratory. Most of the students had a positive grade when planning and carrying out the laboratorial activity (B.1).

As referred before, students were challenged to construct a table to record the results obtained. Only 5 students built a well-presented table – but most of them, 15 students, presented incomplete or poorly organized records (as the examples shown in Table 3.b), therefore obtaining half the score (B.2). As a follow-up, students were challenged to compare the various results from the other groups (B.3a), and they did effortlessly. In conclusion, four of six groups obtained consistent results. Accordingly, most students obtained the maximum score in this activity phase. Debating the encountered difficulties in plastics identification (B.3b) was a considerable challenge. Thus, the score was very uneven: 6 students had a maximum score, 8 scored in the middle, 5 had less than half points and 1 student had no points at all. This inquiry-based activity was developed to engage students in the scientific-oriented activity. However, as expected, since this is a new dynamic implemented among these students, the results demonstrate that there was a general lack of reflection, indicating the need to work further, aiming to reinforce analytic and critical skills, once these are essential to the development of inquiry-based activities.

Furthermore, due time management issues, only about half the students presented the final activity (B.3c), which consisted of drafting a script (a leaflet or a poster) explaining how canteen users can separate plastics and the reason of its importance (Figure 4).

Overall, students who participated in this activity presented good and creative work. The records produced by students, as a group, included drawings, or schemes, with messages of encouragement and awareness to recycle the plastics in water bottles. The slogans and images created

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by them had the quality and creativity one could expect from an awareness campaign (Figure 4).

A

B

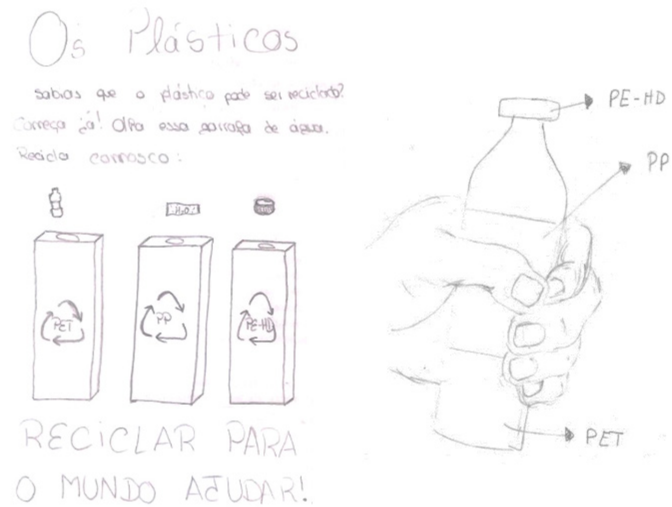

Figure 4. Examples of posters and slogans of the awareness campaign [(A) Plastics: Did you know that plastic can be recycled? Start now! Look that water bottle. Recycle with us.; (B) Recycle to help the world!]

Discussion

In this research, we tried to acknowledge arguments given by students in discussing the use of plastics in society and how they implemented a protocol for qualitatively identifying different polymers via an inquiry-based activity. During the role-playing debate, students presented arguments in favor of the use of plastics – namely arguments based on features of plastics that constitute the advantages of their use. In the case of arguments against the use of plastics, students underlined their enormous waste and the consequent environmental impact, claiming for alternatives replace plastics (e.g. paper and glass). In both cases they presented arguments that fit the actions required by each category. The arguments presented were apparently different, nevertheless met and focused on the necessity of revising the use of plastics in the awareness campaigns.

Even though students plan was to carry out the laboratory activity with a considerable degree of autonomy, it was found that data gathering, and recording was not always appropriate and complete. Students had some difficulty identifying plastic present in the bottle label (PP), but they managed to identify other types of polymers present in a water bottle (PET and PE-HD). Despite the accuracy of the results, students were not able to make a critical reflection on the possible sources of error.

The area of polymer chemistry has occupied a central position among many societal challenges. The role of synthetic polymers is crucial for example, for clothing industries, since they easily replace the use of natural fibers and polymers. Currently, new challenges have been introduced in this area, namely the development of semiconductor materials, hybrid composites and materials, tubular biomaterials and sustainable eco-materials. The inclusion of these contemporary themes in pre-university curricula indicates that much of the current knowledge of chemistry cannot be separated from its practical applications. Some research (Mc Ilrath *et al.*, 2012; Noiwong and P. Phinyocheep, 2012) has shown favorable results when applying an inquiry-based approach to the teaching of polymers. According with Mc Ilrath, Robertson and Kuchta (2012) results, we also had encouraging results when we developed and implemented an inquiry-based activity in order to qualitatively identify different polymers present in a bottle of water. In our case, the inquiry-based activity was at the same time a way to aim some learning objectives and skills defined on curricula such as "Polymer characterization as a macromolecule formed by monomers' repetition"; "differentiate natural from synthetic polymers"; "search about advantages and limitations of plastic recycling and communicate findings"; "Characterization of polymers according families and relate those families with monomers' functional groups" (Direção Geral de Educação, 2018). Additionally, a way through which students addressed scientifically oriented questions about plastics; examined sources of information to observe the existing evidence; and planned and carried out investigations to gather evidence. The formulation of explanations for evidence was not well achieved. As mentioned above, many researchers (Avraamidou and Zembal-Saul, 2010; Cuevas *et al.*, 2005; Howes *et al.*, 2009; Liang and Richardson, 2009; Smolleck *et al.*, 2006) acknowledge essential features of classroom inquiry applied across grade levels – one of these features is the ability to communicate and justify explanations. This skill was also underexplored in this activity, thus in the future complementary activities will take place.

Final Considerations

It is expected that many of the students who choose to take the Chemistry course during their final high school year will be interested in pursuing their Chemistry studies in college. This way, the study of polymers, in an inquiry-based approach, makes it possible for them to engage in activities in which they develop their knowledge and understanding of scientific ideas, together with an understanding of how scientists study the natural world (Luera and Otto, 2005). However, while research recommendations advocate that teachers should spend more time using an inquiry-based approach that includes problem-solving contexts and less time in the didactic presentation of facts (Southerland *et al.*, 2003), our work suggests students require more practice to be familiar with this approach. Literature and our results suggest that inquiry-based learning, usually begins with an orientation phase and flows through conceptualization, investigation and finally the conclusion phase is very demanding for students because each one of these phases – plus the discussion phase - that can be present at every point during the inquiry-based activity – requires different types of knowledge, skills, and competences from students. Students had difficulty in collecting and recording data, in an appropriate and complete way, as well as communicating and justifying explanations. This reveals that students' requested development knowledge, skills and competences, in order to reach a good performance in inquiry-based activities, requires more time and familiarity with the pedagogic approach/activity and a plethora of further educational experiences. Furthermore, teachers have insufficient experience with inquiry in a formal scientific sense and possess very naïve and informal conceptions of inquiry-based instruction (Southerland *et al.*, 2003; Anderson, 2007; Blanchard *et al.*, 2009; Windschitl, 2004).

Although several aspects of the implementation of this inquiry-based activity need to be revisited, opening the doors to the development of complementary activities and enlarging the number of participants, since the main objective of the chemistry program for school year 12 is to stress the importance of chemistry and its multidisciplinary aspects. We believe that our inquiry-based activity gives a contribution with perspectives and pedagogic innovation for teaching polymer concepts through an inquiry-based approach that might be useful to many teachers.

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