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March 2, 2020

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Dear Editor,

Here we submit the revised version of our manuscript. We have faced some unforeseen difficulties with preparing it, and this has delayed the process. We apologise and thank the flexibility offered by the journal to advance on it. We would like to make you aware that after language editing and extensive work on the manuscript, some of the sentences included in the initial reply to the reviewers have been slightly modified, but the content is the same.

In this version of the manuscript, we have included new references, as requested by the reviewers. We think that both the pedagogical and scientific parts of the work are better supported now. Also, we have made an effort to provide complete evidence of the success of our work among the students. We have introduced some references to previous works that had highlighted the need for new teaching materials on this topic. To our understanding, this earlier work justifies the development of the material that we present here.

We would like to thank both the editorial work and the feedback from the reviewers. We consider that in this case, the review process is helping to improve the original manuscript significantly. Also, it has helped to expose better the work and its usefulness to potential teachers using it.

Thank you for your consideration. I look forward to hearing from you.

On behalf of all the coauthors,

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Associate Professor
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Geosci. Commun. Discuss.,
https://doi.org/10.5194/gc-2019-12-AC1, 2019

Interactive comment on "Ozone measurement practice in the laboratory using Schönbein's method" *by* Ignacio Arturo Ramirez-Gonzalez et al.

Ignacio Arturo Ramirez-Gonzalez et al.

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First of all, we would like to thank the reviewer for the constructive feedback on our manuscript. Replies follow:

General comments: I am not commenting on the scientific content of the method presented, as it is not my field. From a scientific communication and science outreach perspective, various aspects remain unclear; a specific reason for choosing to use the 19th-century method is implied but not elaborated on,

The main reason for choosing the 19th-century method is because it is a traditional way to teach about the history of science and at the same time learning by doing about the environment, the atmosphere and air quality. Moreover, this methodology lets to

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Discussion paper

combine teaching on chemistry and physics together (a chemical reaction is the basis to measure a chemical compound resulting from a photolytic one), meanwhile the main methodologies used nowadays are based only on physics (just by using UV light). Also, it is the most economical. The price of the cheapest ozone measuring device is € 600, which is an unacceptable budget for many high school laboratories around the world. However the practice here presented only costs €00 for 1000 people.

the presentation of the method of delivery is somewhat jumbled and I see no evidence that the approach itself is effective beyond the authors asserting that it was (and which they attribute to the students and teachers involved rather than their own approach) or that it has been properly evaluated in this respect. There is certainly potential here to produce interesting information about the efficacy of the technique in communicating this topic to students, but much more information and a thorough evaluation of this is needed.

We acknowledge that the reviewer is right here. However we would like to point out that measuring the effectiveness of the learning of the students was not the main purpose of this work. Our aim is to develop a teaching approach for something that was not taught before and to perform a scientific outreach activity.

That said, we think that the pieces of evidence that we present, although do not correspond to usual assessments of pedagogical effectiveness, are reasonable and good enough. It is necessary to have into account that it is hard to compare the effectiveness of teaching new content when there was not a previous alternative hands-on approach to do it.

Trying to address the request by the reviewer about extra information, we now include in the new version of the manuscript new statistical information about the perception of the students on the previous teaching of the contents associated with the method here presented. This is now in the Introduction and includes a new figure (see figure 1) about the perception of the students on the previous teaching of these concepts.

Supporting information from the literature around the value of such activities (e.g. raising science capital) could also be included.

As requested by the reviewer in the new version of the manuscript we have included a more complete discussion on this and we cite appropriate literature.

Specific comments: These are given in the attached file.

Page 1, line 12 State the educational level.

Now, as requested, we make clear the educational level. The new sentence reads: 'Usually, the study of the atmosphere at these educational levels (from 13 to 17 years)'

Page 1, line 15 Taught where?

Now, as requested, we make clear that we refer to high schools.

Page 2, kine 26 This implies that it is familiar to children under the age of 11.

We have rewritten the sentence to make clear that we only refer to high school students.

Page 3, line 1 What is the evidence for this?

Now we include evidence of this from the surveys completed by the students (including a new plot in the Introduction) and provide new references existing in the literature that support our statement.

Page 3, line 5 What age range is this assuming?

Please, refer to the reply to the first question in 'Specific comments' of the reviewer.

Page 3, line 10 It's not clear what this means.

We have rewritten the sentence and now it reads: 'Also his practice can be used to make students more familiar with the daily work of scientists as this method is currently used when dealing with the recovery of old meteorological data.'

Page 3, line 17 How many high schools? Were these characteristics true of the survey *respondents, or the populations of the high schools?*

We thank to the reviewer for pointing this out, as it has let us spot a mistake in the text. Actually, the age of the students was 12-19 instead of 14-19. We have updated it in the text. Also, the number of high schools is now specified previously in the Introduction.

Page 3, line 18 What did the other 14 questions address?

Now, we include the full survey as supplementary material.

Page 3, line 23 The values are given are different. Were statistical tests performed to ascertain that there was no significant difference?

It was not our intention to get any statistical inference or to make any statement on the statistical significance of the differences. We just want to say that the values obtained are similar. We have clarified it in the new version and now the sentence reads: 'produced a very close value to the one of the previous question'

Page 4, line 10 What is the source for this information?

We now cite the corresponding work.

Page 5, line 3 What are these? If they are to be explained later, it would be helpful to clarify this.

We understand the question by the reviewer, but we do not envisage a way of presenting it better than the current one, because the explanation about the level is under the next subsection that is exactly the next line in the document. However, we are open to suggestions on how to improve it and to incorporate it in future versions of our manuscript.

Page 5, line 5 Who is the simple test for, in this case? There appears to be some contradictory information around this.

This was already explained in the submitted version of the manuscript under the corresponding subsection. We do not appreciate any contradiction, but as for the previous question we are open to modifying it, if the reviewer can point out better where it is and if he/she continues to consider it necessary.

Page 7, line 12 It's not clear what this means.

We have rewritten the sentence to make it clearer. Now it reads: 'This level differs from the more advanced level in the fact the strips are not made by the students. This part is not included at this level, because of the potential difficulty accessing all the materials and the necessary laboratory work behind this.'

Page 8, line 2 How accessible is this, for example for use in schools?

We have clarified this and now the sentence read: '(O3Meter, which can be downloaded from Google Play or from the Github repository and installed on an Android device or on a personal computer)'

Page 8, line 25 This information needs to be given earlier.

We have moved this information to the Introduction.

Page 8, line 25 How was this measured?

It was not our aim to imply an objective measurement of this. However, the answers to the question "Would you like more information about it?" presented in Figure 2, show that after the activity 90.5% of the students wanted it. Also, from a more subjective point of view, we consider that the activity was a success as its development in several high schools made headlines in local newspapers. Now we also cite these news. Therefore, we have rewritten the sentence to make all this clear and now it reads:' As previously discussed, we presented the practice in 10 Galician high schools (to more than 350 students) and it was well-received. Figure 2 shows how after the activity 90.5% of the students wanted more information about it. Also, we consider the activity successful in terms of scientific outreach as its development in several high schools made headlines in local newspapers [Diario de Lemos, 2017; La Voz de Galicia, 2017]'

Page 8, line 30 This fits within the wider context of impacts of outreach activities on school students, e.g. https://www.tandfonline.com/doi/full/10.1080/09500693.2018.1473659

We thank to the reviewer for pointing out this relevant work by Vennix et al. that we did no and now cite in our manuscript.

Page 10, line 3 What was the impact of your method? If you were successful because of the attitude of the students and school staff, what is the evidence that your approach itself was successful in engaging students and raising their subject awareness? Supportive school staff is undoubtedly hugely valuable but effective approaches will also reach disengaged students.

The reviewer is right when points out that the a priori attitude of the students of the students is hard to measure and not enough studied in the results that we present. Therefore, as this is not relevant for the main purpose of the work, that is to present a new laboratory practice combined with an outreach activity, we have removed it from the manuscript.

Page 10, line 7 How large are these groups?

We have clarified it and now it reads: 'The cost per application ranges between 200 and 300 euros per group of 1000 students (1000 strips for one year)'

Page 10, line 12 It's not clear what this means?

After reading this sentence again, we consider that this topic has already been discussed in the manuscript and therefore we have removed it from this part. Moreover, we agree with the reviewer that it was poorly written making the reader feel confused about its meaning.

Page 10, line 15 What is your evidence that this has occurred?

We are not making a hard statement here and it was out of the scope of this activity the measure how effective was the teaching or learning of the students, as we make clear at the beginning of our manuscript. Indeed, we do not state that the students have actually deepened their knowledge, but that this activity let them to do it. If the reviewer considers our statement as too bold as it is right now, we are open to rewrite it, but we consider that as it is, it reflects this accurately.

Page 11, line 4 Did you undertake any evaluation of this?

No, we did not it. Again, this is out of the scope of this work and we state that this is simply an expectation.

Technical comments: The general English needs some improvement throughout.

Our manuscript has undergone professional language editing, but we have made an extra effort to improve it in this new version.

Interactive comment on Geosci. Commun. Discuss., https://doi.org/10.5194/gc-2019-12, 2019.

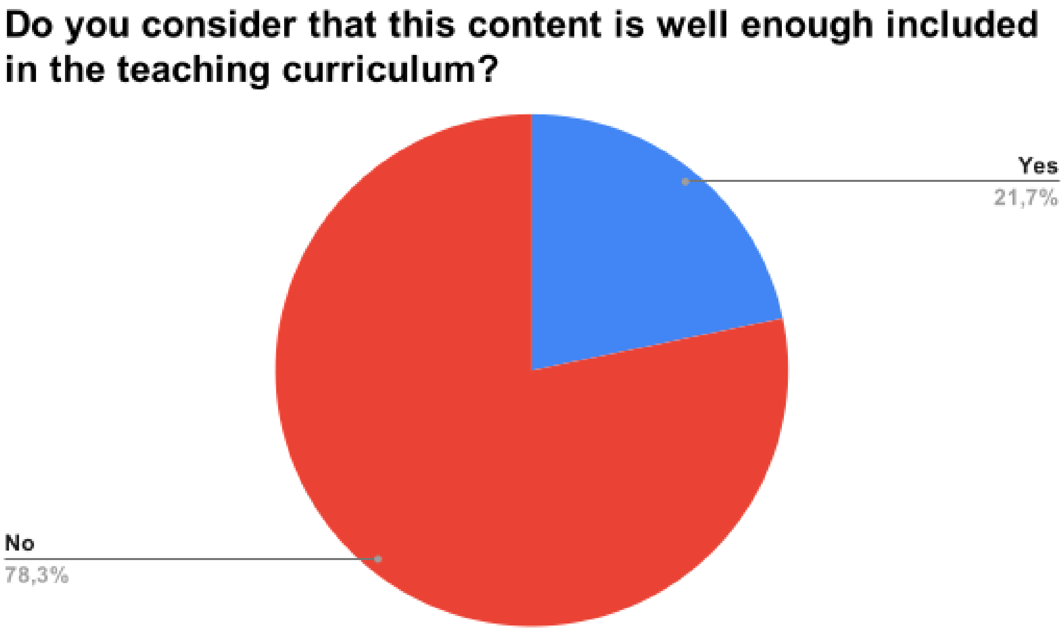
Do you consider that this content is well enough included in the teaching curriculum?
Yes
21,7%
No
78,3%

Fig. 1.

Geosci. Commun. Discuss.,
https://doi.org/10.5194/gc-2019-12-AC2, 2019

Discussions

Interactive comment on "Ozone measurement practice in the laboratory using Schönbein's method" *by* Ignacio Arturo Ramirez-Gonzalez et al.

Ignacio Arturo Ramirez-Gonzalez et al.

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Dear Editor,

First of all, thank you for your comments and constructive feedback. We have improved our manuscript according your suggestions where it is possible. Next we include specific replies to each question.

Schönbein method. On the one hand, many readers want to know the specific reason- for choosing this historical method. There are many examples of experiments, ideas or elements of the history of science that can be used today for the teaching or communication of science. On the other hand, other readers want to know more aboutthis method of measuring tropospheric ozone and, in particular, if it is possible to recover *or get (long) measurement series using the old data that will be preserved in the notebooks of the old observatories that used this method.*

The main reason for choosing the 19th-century method is because it is a traditional way to teach about the history of science and at the same time learning by doing about the environment, the atmosphere and air quality. Moreover, this methodology lets to combine teaching on chemistry and physics together (a chemical reaction is the basis to measure a chemical compound resulting from a photolytic one), meanwhile the main methodologies used nowadays are based only on physics (just by using UV light).

Also, it is cheaper method. The price of the cheapest ozone measuring device is € 600, which is an unacceptable budget for many high school laboratories around the world. However the practice here presented only costs € 200 for 1000 people.

The issue of data recovery is now included in Conclusions and reads: 'Note the existence of previous work recovery data on which measures based on the method of Schönbein (Linvill, 1980; Cartalis, 1994; Pavelin, 1999) are included. Today still exist ozone data sets that are not recovered.'

In section 4.2, software made by the authors is briefly described and the work of Ramírez-González et al. (2018) is cited. In the caption of Figure 5, the name of this software appears as "O3METER". I am aware that the authors want to publish the detailed description of the software in another article. Perhaps this work is already accepted or published. In any case, I think you should include the name of the software in the main text and offer some additional information to the reader (a more detailed description, a website where some version of the software can be downloaded, etc.)

As mentioned in the response to reviewer 1, the manuscript has been modified and added the following: (O3Meter, which can be downloaded from Google Play or from the Github repository and installed on an Android device or on a personal computer) '

Interactive comment on Geosci. Commun. Discuss., https://doi.org/10.5194/gc-2019-12, 2019.

Ozone measurement practice in the laboratory using the Schönbein's method

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Abstract. We present a laboratory technique that can be used to measure tropospheric ozone, following a traditional method developed by Christian Friedrich ~~Schönbein~~ Schönbein in the 19^{th} century. ~~The practice is described with two~~ We include a description to do it with two different levels of complexity (~~the~~ advanced and basic) to adapt it to the capacity of the students. The advanced level includes the production in the lab of paper strips as they were produced in the 19^{th} century while ~~thebasic~~ the basic level does not~~), and~~ . This practice is suitable for use by both ~~high-school~~ high school and first-year undergraduate students. The ~~overall~~ aim is to familiarise students with both the scientific ~~methods involved and the related~~ method and the concepts of pollution and ~~ozone~~climate change. This technique was developed and presented in high schools during a communication campaign to celebrate the annual Galician Scientist Day~~and based on the detected need for a better understanding of the problems of climate change and pollution~~. Moreover, we discuss the teaching approach used and the results ~~obtained from~~ from collected surveys and feedback ~~obtained~~ received from the students and teachers.

1 Introduction

~~Usually, the study of the atmosphere at this educational levels and from the practical point of view is focused at best on theuse of cheap and small weather stations that measure physical variables (e.g. temperature, pressure, humidity). However thestudy of the atmosphere and the environment needs of knowledge on its chemical composition. For example, global warming and ozone depletion are issues broadly taught but mostly from a theoretical approach (documentaries, lectures...). That said, this laboratory practice introduces a hands-on approach to the study of the chemical composition of the atmosphere, letting the students be much more familiar with it.~~

This laboratory practice is intended as an additional tool to assist in the teaching of atmosphere and environment science. Thus it is presented as project-based learning with proven competence, as defended in previous works (Blumenfeld et al., 1991; Bell, 2010). Using this learning method, students developed their skills through “learning-by-doing”.

Ozone (O_3) occurs in gaseous form in the Earth’s atmosphere (Fabian and Dameris, 2014; Añel, 2016b). An allotropic form of oxygen (O_2) formed by three oxygen atoms, it has a blueish colour, which is only observed it is possible to observe when it is found in large concentrations. It is well known for its existence in the famous "ozone layer" of the stratosphere (Añel, 2016a), which protects us from ultraviolet radiation, thanks to the fact that its absorption band is in the ultraviolet spectrum (Hartley Band: 200 - 300 nm). However, our work the work that we introduce here focuses on O_3 in the troposphere, the atmospheric layer closest to the Earth’s surface in which all living organisms are found.

This O_3 that surrounds us, and which we breathe, does not offer protection in the same way that the stratosphere doesit does in the stratosphere. The difference lies in its ability to act as a powerful oxidant, and in large concentrationsit . In large concentrations, O_3 can affect the respiratory systems of living organisms, and alter the coverage and healthiness of vegetation. The proliferation of heavy industry has been linked with increased concentrations of confusion among pupils about this different role of O_3 has been well documented (Myers et al., 2004).

It is well documented a positive trend in the concentration of tropospheric O_3 since the 19^{th} century because of the proliferation of heavy industry, from average values of 10-15 ppbv in the pre-industrial era to 30-40 ppbv todayppbV in the preindustrial era to near 50 ppbV nowadays (Marenco et al., 1994).

Measurements are Among other methods, preindustrial measurements were possible using the Schönbein’s methodSch¨onbein’s technique, named after Christian Schönbein, who developed the method it and also discovered O_3; his . This is a rudimentary method based on paper strips impregnated with potassium iodide solution a solution of potassium iodide (KI) and starch (($C_6H_{10}O_5$) $_n$- (H_2O)) in distilled water. There are several versions of the methodtechnique, which vary in the concentrations of starch(($C_6H_{10}O_5$) $_n$- (H_2O)), potassium iodide (KI), KI, and paper used. The precision of the measurements varies considerablyas As a result of the different concentrationsused. Among the different these different concentrations, they existed several types of paper available, that strips available to perform the measurement, which let different levels of accuracy. The one produced by Jame de Sedan is was traditionally the most widely used and is recognised as that which allows the greatest because it allowed the highest precision (Bojkov, 1986).

Exposed to the open air open air (but protected from sunlight), the KI on the strip reacts with the O_3 and the humidity existing in the environment. The strips are strip is exposed for a given time, period, usually 12 or 24 hours, after which they it must be collected, taken to a laboratory, and dipped in distilled water, which causes them to turn . After it, immediatly, the strip which turns a shade of purple related to as a function of the concentration of O_3 present (Bojkov, 1986). By comparison against a given scale (similar to that shown in Figure1 1) a numerical value can be obtained and linked to an existing O_3 concentration in the environment. These values were generally recorded as O_3 in the logbooks of observatoriesas discussed previously (Añel et al., 2012; Linvill et al., 1980).

It is clear that the (Linvill et al., 1980; Añel et al., 2012, 2017). The choice of numerical value from Fig.1 . 1 involves a great deal of subjectivity , because it depends on the observer, and each one has different physiological features (Solomon and Lennie, 2007)

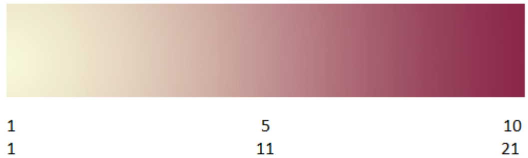

Figure 1. Typical scale used to compare colours using two scales: Schönbein (top line) and Berigny (botton line).

. Different people have and different abilities to distinguish colours, and the (Solomon and Lennie, 2007). Also, the existing ambient light can also have an effect. Only affect the measurement. Therefore, only with experience, can an observer an observer can reduce the error associated with this the subjectivity.

Ozone Usually, the study of the atmosphere at educational levels (from 13 to 17 years) is focused at best on the use of cheap and small weather stations that measure physical variables (e.g., temperature, pressure, humidity). These kind of stations are affordable and convenient because of size and installation. However, the study of the atmosphere and the environment needs knowledge of its chemical composition. The lack of a hands on approach to complement the theoretical learning of the composition and chemistry of the atmosphere can lead to a knowledge gap. Sometimes, this is hindered by the lack of understanding of some essential words and concepts by pupils (Österlind, 2005). For example, climate change and O_3 depletion are issues broadly taught in high school classrooms but mostly from a theoretical approach (documentaries, lectures, etc.) The misconceptions on these issues among the students are well documented (Boyes and Stanisstreet, 1993; Boyes et al., 2004b; McCaffrey and , and they seem to remain through the years. This confusion was manifest also in surveys fulfilled by a group of students to whom we presented the practice here described (see Figure 2). In line with this, it has been noted the need of developing specific materials to teach better these topics (Papadimitriou, 2004), and again the need to include more content on these issues in the curriculum was acknowledged in the surveys that we carried on (see Fig. 3).

Moreover, O_3 and air quality are generally unfamiliar among students over the age of 11; neverthelesshigh school students; nevertheless, it is a topic that canarouse can arouse their interest due to the potential issues involved (Shepardson et al., 2009; Punter et al., 2 . Their knowledge of climate change tends to vary and is often contradictory, and they tend to confuse it with the problem of the ozone layer. One of the reasons for advancing this technique is to expose them to these topics by supplementing their knowledge of scientific methods (Boyes and Stanisstreet, 1993).

We herein present a technique based on Schönbein(Boyes et al., 2004a; Shepardson et al., 2009; Punter et al., 2011; Hagedorn et al., 201 . Therefore, to address this issue, we introduce here a laboratory practice, a hands on approach that serves as an additional tool to the study of the chemical composition of the atmosphere, based on the old 19^{th} century Schönbein's method of measuring tropospheric ozone. The goal is to let the students be much more familiar with this topic. We present the practice as project-based learning, a technique with proven competence (Blumenfeld et al., 1991; Bell, 2010). Using this learning method, students developed their skills through "learning-by-doing".

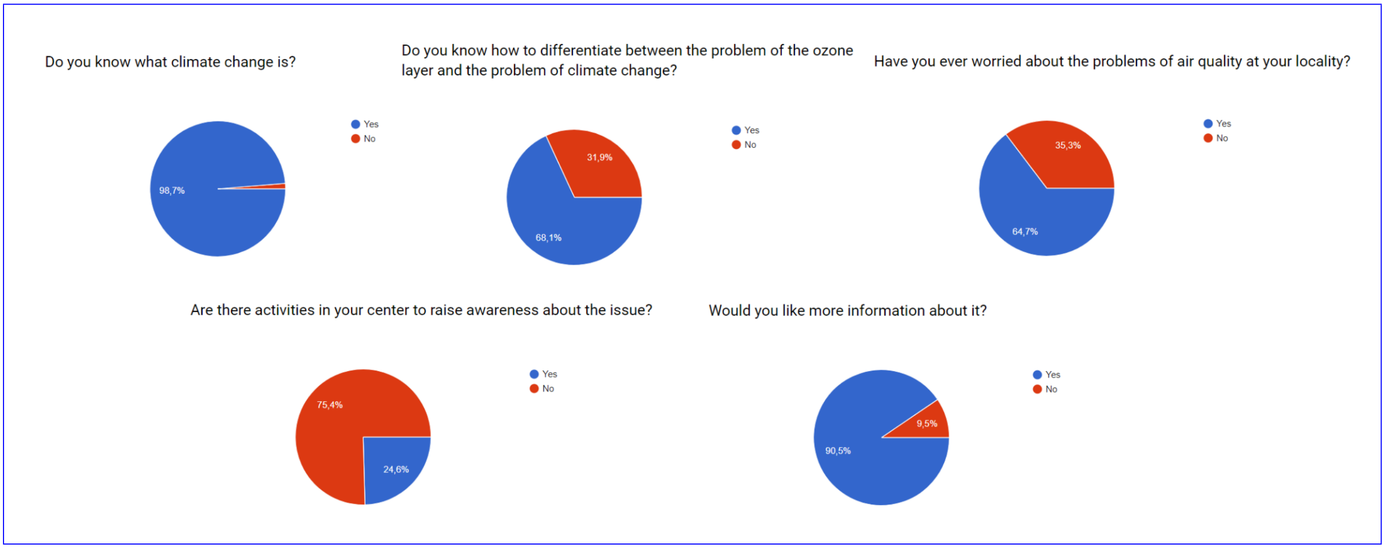

Figure 2. The five most relevant questions related to knowledge acquired through practice: "Do you know what climate change is?" received almost universally positive responses; "Do you know how to differentiate between the problem of climate change and the problem of the ozone layer?" resulted in around one-third negative answers; "Have you ever worried about the problems of air quality in your neighbourhood?" received the proportion of responses as the previous question; "Are there activities in your area to raise awareness of this issue?" produced three-quarters negative response; "Would you like more information about it?" received almost universally positive answers.

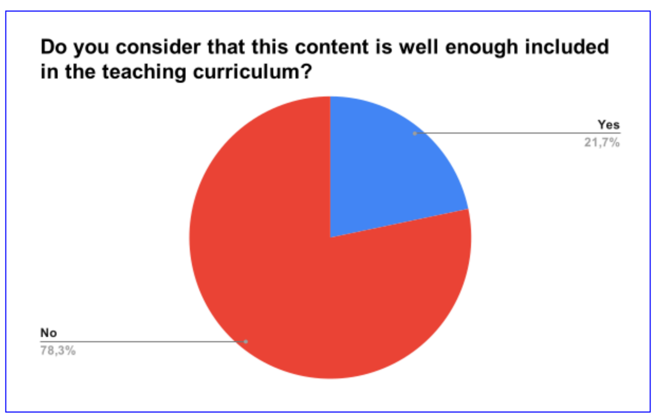

Figure 3. Perception of the pupils on the contents included in the curriculum on the topics of climate change and atmospheric pollution.

To make it more accessible to students, we propose two different levels ~~of test~~for this laboratory practice. The first could be used by high school students (age range of 12-16), in which the measurement and its subsequent validation are developed using ~~Schönbein~~the Schönbein's method. The second is more advanced (from high school onwards), and includes the entire process including manufacture and use of the strip~~. The didactic~~ , making use of concepts of inorganic and atmospheric chemistry. The main difference is that during the basic one the students only measure; meanwhile, the advanced level consists of the entire process of creating the strips and explaining the concepts of chemistry involved and the method itself. The educational objectives are to measure O_3, to teach the measurement of environmental pollution to students, and to highlight the difference between subjective and objective ~~measurement~~analysis. We propose the use of this scientific method to identify these differences.

This practice can be used as experience and demonstration of the development work that underpins all scientific activity, ~~allowing the assessment of the work of any scientist to be assessed~~which allows students to familiarise themselves with the scientists' profession, as this method is currently used when dealing with the recovery of old meteorological data. The authors are well aware of the existence of an old technical report (Fukushima, 1993) on this topic. ~~We nevertheless~~ Nevertheless, we propose to take the work a step further~~by incorporating~~ . Our work incorporates photos and graphics, ~~performing a survey, developing specific software~~ add the possibility to apply new technologies (a specific free software, helping to understand how science works (Pfaffman, 2008)) and lets to achieve objective measurements. Also, we gave to the students contribute to a small pedagogical study and a communication campaign~~, with the clear aim of achieving objective measurements.~~ .

We presented the technique to students in ten Galician high schools ~~and at the same time we conducted surveys (243 students)to ask students~~ (approx. 350 students). From this group, 243 students accepted to reply to a survey about their knowledge of general environmental issues such as climate change, pollution, and ozone, and the steps taken to raise awareness of these issues. The age range of the students who responded to the survey was ~~14-19, with thes ame gender balance and education system (of the Regional Government)in all the high schools~~12-19, with a similar gender balance (51% males, 49% females). The survey (~~which could be completed in person~~ we offered the possibility to fulfil it in person and deliver it in a printed form or online) consisted of 19 questions (see appendix 1), of which we discuss the five most relevant in terms of the knowledge to be acquired through the use of the technique. By analysing the responses, we obtained the following results (see Figure~~2).~~ 2): Taking each question in turn, "Do you know what climate change is?" received an almost universally positive answer (98.7%); "Do you know how to differentiate between the problem of climate change and the problem of the ozone layer?" resulted in one-third negative answers (31.9%); "Have you ever worried about the problems of air quality in your neighbourhood?" produced a very close value to the one of the previous question (35.3%); "Are there activities in your area to raise awareness of this issue?" produced three-quarters negative response (75.4%); "Would you like more information about it?" received almost universally positive answers (90.5%).

These results reinforce the idea that students have gaps in their knowledge of these subjects and that they know they have them. ~~It is also clear that they require~~ Therefore, they are necessary activities to raise their awareness of ~~them because they know they do not have all theinformation they need~~these issues. Hence there is a need to establish this kind of practice ~~in order~~ to meet the needs expressed by students.

In the following sections, we discuss the ethical considerations ~~relevants~~ relevant for the work here performed, expose the teaching approach used and the results obtained with it. Finally, we extract some conclusions on this experience and the result of the laboratory practice.

~~The five most relevant questions related to knowledge acquired through practice: "Do you know what climate change is?" received almost universally positive responses; "Do you know how to differentiate between the problem of climate change and~~

the problem of the ozone layer?" resulted in around one-third negative answers; "Have you ever worried about the problems of air quality in your neighbourhood?" received the proportion of responses as the previous question; "Are there activities in your area to raise awareness of this issue?" produced three-quarters negative response; "Would you like more information about it?" received almost universally positive answers.

2 Ethical considerations

he During this research, we guaranteed the anonymity of the persons involved in the surveysfor this research, both during the development of the project and regard-ing , assuring that they were anonymously collected and processed. Also, anonymity extends regarding the preservation and publication of the resultswere guaranteed. The surveys were collected and processed anonymously. Because of the nature of the experiment, we did not need previous clearance from the commission of ethics of our researchcentre. It was enough research centres. We simply had to follow the rules exposed approved by our university. They the Universidade de Vigo, where the project was funded, and the work developed. These rules are available in the document ‘"Ethical Recommendations in Research by the Universidade de Vigo" (https://www.uvigo.gal/sites/uvigo.gal/files/contents/paragraph-file/2019-06/Ethical_Recommendations_1.pdf).

3 Method

Based on the idea of "learning by doing", project-based learning (PBL) is a student-centred pedagogy that involves a dynamic classroom approach (Blumenfeld et al., 1991). That means students manage all the activities by ownselfsthemselves, gathering information and responding to a10complex a complex question, challenge, or problem. In this case, the topic is air quality, focus in focused on ozone. As an introduction to the activity, a theoretical class is proposed to the students, this is what . After it, all the information related to thelaboratory the laboratory practice is presentedto them and the distribution of , and the groups of students can distribute the work. In the next section, it is explained the laboraty we explain the laboratory practice itself.

4 Teaching method

As previously explained, we have created two levels of test, one basic and one more advanced. We will now Both levels serve the purpose of studying the environment, through a better understanding of O_3 and atmospheric chemistry in general. Moreover, the advanced level includes a part suitable to teach inorganic chemistry in the laboratory, through the making of the O_3 measurement strips by the students. Next, we explain the more advanced one, which also includes the essential elements of the basic version.

Figure 4. Instrumentation and materials (potassium iodide, starch, rods, beakers, balance and stove).

4.1 Advanced level

This level of ~~test~~ the practice is designed for high school and first year college students. The following materials are required ~~to conduct the test (Figure3~~ (Figure 4 shows some of ~~these~~them):

Materials:

- potassium iodide (KI)
- starch ($(C_6H_{10}O_5)$)
- drying paper
- distilled water
- self-closing bags

Instrumentation

- beakers
- balance
- rods
- stove

~~To dry the strips, we propose using boxes of any appropriate material, for example, cardboard, in which the strips are allowed to dry for twelve hours. They are then stored in airtight bags shaded from sunlight until they are used for the measurements.~~

~~The strips should be protected from inclement weather and sunlight, therefore the drying box can also be used to display the strips (with the proper protection).~~

The next stage consists of two parts: making the strips and using ~~then~~ them for the measurements. To make the strips, we follow the instructions of Jame de Sedan (these strips were the most widely used throughout the ~~nineteenth~~ 19^{th} century) in different studies. We use a solution of KI and starch in distilled water, via the following steps:

1. 100 mL of distilled water is poured into a beaker, which is heated up to a temperature of around ~~80ºC~~80 ºC (it should be checked with a thermometer submerged);

2. 10 grams of starch are added to the beaker with stirring until a gelatinous mixture is obtained (taking care not to boil because the resulting chains of polysaccharides could be broken);

3. 1 gram of KI is added with stirring until homogeneous;

4. ~~the mixture~~ The resulting mixture (see Fig. 5) is allowed to cool in a location shaded from sunlight. ~~Once~~ When it is cool, the drying paper or filter strips are ~~added~~ impregnated with it (for example using a brush or dipping them) for about six hours and then removed;

5. ~~, after~~ After it, the strips are removed from the solution and allowed to dry horizontally for two hours (also protected from sunlight and in an environment ~~free from~~ without O_3 ~~(it is~~ as they are already reactive);

6. ~~once dry these~~ When the strips are dry they are stored in ~~self-closing~~ self closing bags.

~~After the~~

To dry the strips, we propose using boxes of any appropriate material, for example, cardboard, in which the strips are allowed to dry for twelve hours. They are then stored in airtight bags shaded from sunlight until they are used for the measurements. The strips should be protected from inclement weather and sunlight. A faster option that can work under certain conditions is to dry them inside a microwave.

After manufacturing the strips, the measurements can ~~then take place~~be done. Because the strips must be allowed to dry, which cannot happen in just a few hours with the traditional technique, it is recommended that the laboratory practice is run in this case over two days.

The procedure for measurement and data collection is very simple. It consists of exposing the strip outdoors, protected from sunlight, for ~~12 or 24~~ twelve or twenty four hours (in this case, ~~24~~ twenty four hours may be preferable due to the timing of the school day). ~~After 24 hours~~Then, the strip is collected and wetted with distilled water~~, which turns it~~. Doing it, it turns from white to blueish purple. The degree of ~~coloration will be as indicated by the colour of the strip. By comparing the colour of the strip with a~~ colouration is compared with the given scale (see Figure~~1)the students~~ 1). Then the pupils can measure the value and enter it on a blank sheet, which we also provide (see Table 1).

~~Example of strips (left: made by ourselves, right: comercial strips).~~

Figure 5. Mixture resulting from the solution of KI and starch in hot distilled water.

Annotation List						
Exposure date	Exposure time	Collection date	Collection time	Visual value	App value	Observations

Table 1. Annotation list

If timeIf it is possible, part of the experiment could involve the students making a series of measurements over a period of time while (e.g., two weeks) to allow the strips to be exposed to measure different atmospheric conditions, which would then . This would help to highlight the changes in O_3 concentration .

and colouration of the collected strips. In order to gain a better understanding of the procedure and of ozone O_3 measurement in general, it would be desirable to compare the values of O_3 obtained with data from the nearest state-of-the-art ozonometer . This (usually available in internet from official air quality monitoring networks). This part would enable students to understand that although O_3 mixes locally in a very homogeneous manner, there can be they can exist considerable differences between different places in the same neighbourhood due to the different various factors that affect O_3it. It would also allow the assessment of the reliability and validity of the Schönbein method. It is furthermore possible to buy a hand-held ozonometer, which is much cheaper than a fixed ozonometer, to take measurements measure in situ. For example, the S200, S300, S500 models from Aeroqual (https://www.aeroqual.com/) have been shown to be useful (Lin et al., 2015).

Figure 6. Example of strips (left: made by ourselves, right: comercial strips).

4.2 Basic level

This level differs from the ~~more advanced level in the use~~ advanced one in the making of the strips. ~~This part is not used at this level because of~~ It avoids the potential difficulty accessing all the materials and the necessary laboratory work behind this. There is an option to buy the strips ~~froma~~ from a supplier (for example Sigma Aldrich ~~«~~"Potassium Iodide Starch Paper ref.37215~~»~~") and to perform the measurements using ~~these strips~~them. In this way, even students in the first year of secondary school could carry out the experiments (Figure~~4~~ 6 compares strips made by ourselves with commercially available strips to highlight the differences). The remainder of the technique is the same as it is for the advanced level.

Our own experience suggests that it takes some time to acquire the necessary degree of consistency and accuracy in the measurements. The availability of photographic and computational tools means that it is possible to eliminate all human error in terms of colour choice, and a method free from human subjectivity is thus possible.

To this end, our setup consists of a camera assembly, under controlled light and focal length conditions, and a software package developed to ensure the precision of the result according to the correct shade of colour. The software (O3Meter) is avaiable from Google Play (https://play.google.com) or a Github repository (https://github.com/EPhysLab-UVigo/O3METER) and works on Android devices or a personal computer. It uses a graduated scale of the whole ~~spectrum that is possible when the strip is used; from~~ colour spectrum that the strip can take. From this, a ~~pixel-by-pixel~~ pixel by pixel scaled comparison algorithm provides an output with a numerical value within that scale (Ramírez-González et al.). This application (see Figure~~5~~ 7) facilitates the use of the technique by students~~- in essence~~. In essence, all they need is a mobile phone with a camera,

Figure 7. Capture of the output by O3METER (mobile version).

a shoebox and a light from a mobile phone, or possibly a torch or some other device with a light bulb (e.g., ~~asecond~~ a second mobile phone with a ~~light~~lamp). Everything is assembled by placing the strip inside the box, and photographs can be taken through an opening in the box (a second hole is required to allow illumination of the strip by the light source). It is understood that errors of measurement are possible, and there could be some variability in the controlled lighting conditions~~, but~~. Still, for educational purposes, it is also useful and entirely acceptable to discuss these errors. The image obtained is then processed using the software, and ~~objective ozone results can be obtained~~an objective ozone measurement is achieved.

4.3 Discussing the results

After obtaining the results, the students must debate the subjectivity of the measure. As mentioned ~~above, the measure~~ earlier in this paper, the measurement depends very much on the capacity of the observer. ~~Two different observers could see two different shades in the colouration of the strips, and for this reason~~For this reason, we propose the following activity after the first ~~24~~ twenty four hours of the experiment.

~~Different students would~~ Different students should evaluate the colour of the strips and write down the results without discussing them with anyone. These results would then be shared, and the difference between the ~~different measures would be~~ measurements debated. To expand on the possibility of different measurements, the observation conditions could be altered (more or less lighting, less observation time, differences when comparing using the given scale, etc.). All this information would be noted ~~, and~~ and would form part of the debate allowing different points of view to be discussed.

It is in this ensuing debate that we would wish students to become familiar with the scientific method (Añel, 2019)~~, where allexperiments~~ . The differences would help them to be aware that all experiments to be compared must be carried out under the same conditions and with some understanding of the ~~attenuation (errors)that accompany~~ bias that accompanies each measurement.

5 Results

As previously discussed, we presented the technique in 10 Galician high schools (to more than 350 students), and it was well received ~~.~~

~~Figure6 shows the response to other two important~~ in the student environment and by local media (Diario de Lemos, 2017; La Voz de Gal . Figure 8 shows the responses of the students to another two crucial questions. Taking each question in turn, "Are there other activities in your high school that let you learn about this topic?" received almost three-quarters negative answers. After presenting the practice and the issue of O_3 measurement to the students, the question "Would you like to know more about this topic?" received nine out of ten positive responses. By the same token, we can assume that there is a lack of activities and that students want more events like ~~this~~the one here proposed. Therefore, as Vennix et al. (2018) noted in previous work, the outreach activities by universities (such as the one here developed) can be a great tool to increase pupils motivation towards STEM disciplines.

~~We~~

Additionally, we gathered information about this activity from ~~teachers~~the teachers in the high schools that we visited. As an example, we include next the comments by ~~one of~~ the teachers from ~~the~~ one of the high schools, the IES Pontepedriña~~highschool:~~

~~Capture of the output by O3METER (mobile version).~~

:

~~Results of two relevant questions related to the interest of students about the laboratory practice and aroused interest.~~

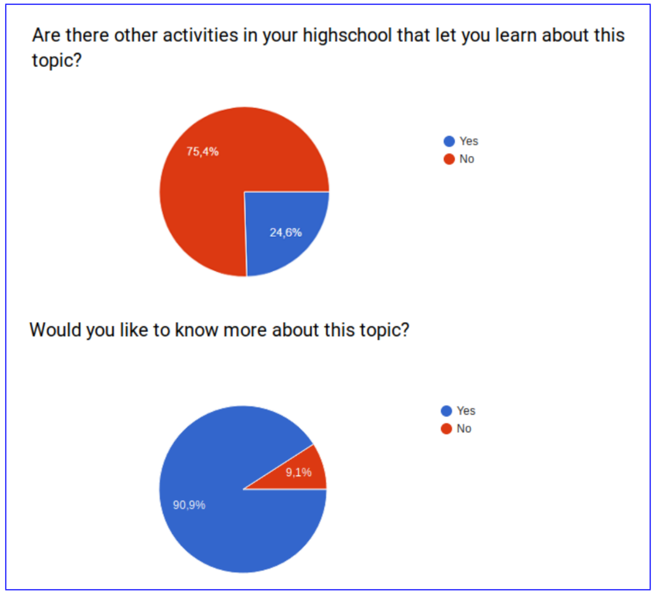

Figure 8. Results of two relevant questions related to the interest of students about the laboratory practice and aroused interest.

~~Figure7~~ *"In general, any activity that is carried out with students and people different from the teaching staff has great value since it reinforces the teacher and the contents that are worked in the classroom. On the other hand, everything that is experimental, or ~~can be seen~~ in some way it is possible to see, it is better for the students provided that it ~~is based on~~ has a theoretical basis (~~normally~~ it usually is better ~~that it be~~ if the theory is taught before the experience, although doing it inversely can be an incentive for the students to continue researching). If ~~also~~ the experience is simple and playful too, then the success of it and the improvement of learning is guaranteed."*

~~*Results of two relevant questions related to the interest of students about the laboratory practice and aroused interest.*~~

~~*Figure7*~~ *Figure 9 shows an introductory class in the technique; here it is being presented to ~~high-school students. We witnessed the initial ignorance of the subject that the students had, and the curiosity that was awakened in them when they took part in these exercises. We believe that our success was due to the good disposition of the students, together with the cooperation we enjoyed from the high school staff~~high school students.*

6 ~~Discussion and Conclusions~~

6 Conclusions

Our practice has the advantage of being extremely cheap in terms of student/practice ratio. The cost per application ranges between ~~20 and 30~~ 200 and 300 euros per group of ~~students~~1000 students (1000 strips for one year). The use of ~~low-cost~~ low cost materials and the simplicity of assembly are most attractive when the test is used in the classroom. Most importantly, teachers can follow the instructions and carry out the activity themselves.

Figure 9. One of the authors presenting the technique to students of Santiago Apostol School in 2017.

This work was presented during ~~the last~~ a meeting of the Royal Spanish Society of Physics in the Symposium on Teaching of Physics, and some of the attendees approached us, requesting the information necessary to develop this laboratory ~~practicein their highschools. This demonstrates that there are interested in activities like this. A way of seeing close up atmospherics science to students, potential scientists.~~ practice in their high schools.

This practice allows students to become familiar with the scientific method, with questions of physics and atmospheric chemistry, concepts of atmospheric pollution, and basic meteorology. It also allows them to deepen their knowledge of the history of science, related to the hole in the ozone layer, the development of ways to measure air quality, and the influence ~~ofnew~~ of new technologies in measurement~~, for example~~. All this can be done putting into context the existence of previous work on the recovery of old ozone measurements based on the method of Schönbein (Linvill et al., 1980; Cartalis and Varotsos, 1994; Pavelin et al., 199). Also, this practice and all the outreach activities included (visits and talks in high schools and media involvement) helped to raise the science capital (Archer et al., 2015) of the pupils and the general public, something that has been proved extremely necessary (Kudenko and Gras-Velázquez, 2016).

~~Having conducted these experiments~~After conducting these experiments, it is expected that students ~~would have acquired~~ will acquire basic knowledge about O_3 (understanding the difference between ~~‘good’ and ‘bad’~~ ’good’ and ’bad’ ozone, for example), together with an understanding of the scientific method and air quality.

As mentioned above, we have presented the technique to students in 10 Galician high schools (to more than 350 students) and were pleased to see its widespread acceptance. We witnessed the initial ignorance of the subject that students had ~~, andthe~~ and the curiosity that is awakened in them when they develop exercises such as these. We believe its success was at least partially due to the ~~good~~ excelent disposition of the students towards new knowledge, together with the cooperation of the high schools themselves.

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