Discussing discarded models: an integrative teaching resource

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ABSTRACT
This study proposes a kind of teaching resource adaptable to different levels of teaching and training objectives that allows the introduction of contextual issues and concepts of history and the nature of science while providing tools for learning modeling and integrating different kinds of knowledge. A controversial case from science history was sought to develop an integrating teaching activity. The case to find must be one that confront at least two different models to solve a scientific problem or a technological one. Torricelli's theory vs. horror vacui theory as it was modified by Galileo result a useful case to take as content for the teaching activity. Groups of students must argument in favor and against each of theories or models. The proposed activity introduces future teachers in the student's role, considering that they will play the teacher's role when they use similar activities with their future students. Moreover, it trains future physics teachers to integrate modeling, history and nature of science.

Keywords: Contextualization, History of Science, Integrative Teaching, Modeling-based Teaching, Nature of Science.

1 INTRODUCTION

The scientific and technological education that students are expected to acquire in each era is contingent upon numerous factors: educational objectives and levels, characteristics of society, and the adopted epistemological stance. Epistemological positions diversified throughout the 20th and 21st centuries, leading to significant changes in curricula and classroom activities, although changes in the latter tended to be slower.

The so-called "standard view[1]" served as epistemological support for a type of natural science education focused on the products of scientific activity (theories), concerned only with the forms of justification of scientific knowledge, neutral and, consequently, independent of any context.

[1] We use "standard view" following Merrille Salmon in the Introduction to [Salmon *et al.*, 1992]. It refers to proposals of the logical empiricists who moved to the United States at time of WW2.

Philosophers enrolled in the so-called "new philosophy of science" introduced values, knowledge production processes, historical context, and other elements into the analysis of science. Finally, semantic analysis of science focused on scientific models as central elements of epistemological analysis. These three traditions were developed one after the other and then overlapped from the beginning of the last century [Duschl, 2020; Moulines, 2011]. The introduction of history included interest in internal history but also in the external history of science that places scientific developments in their sociohistorical context, noting the relationships that science has with the environment that surrounds those who produced it.

The relevance of scientific models in science education began with semantic developments [Giere, 1988; Balzer *et al.*, 1987, Van Fraassen, 1980]. Regardless of the attention given to these models to characterize human activity, which we call "science", the teaching of natural sciences and mathematics based on models is currently promoted.

From the didactics of science, model-based teaching and teaching based on modeling or model construction are promoted [Justi, 2006; Gilbert; Justi, 2016, Oh; Oh, 2011] as a resource for middle-level education. It has also been shown to be useful and promoted for higher education from academic papers [Clement, 2000] and from curricular proposals like the Council of Chairs of Engineering College in Argentina [2014].

In science teaching, metascientific issues are introduced through those who promote, especially in secondary education, contents of STS or STSE (Science, Technology, and Society or Science, Technology, Society, and Environment) and those who propose the teaching of NOS (Nature of Science, which involves philosophical content). In science didactics, these elements are part of an area known as HPS (History and Philosophy of Science) that links metascience studies with work in didactics [Matthews, 1994; Mc Comas, 1998].

In Argentina, the regulations and curricular designs for middle schools [GCBA, 2015] expressly include modeling as a resource. Depending on the chosen orientation[2], there is a greater or lesser inclusion of STSE and NOS content.

If model-based science education, contextualized and including metascientific reflection is proposed for middle school, it is imperative that teachers be adequately prepared to undertake this task.

This paper proposes a type of didactic activity, exemplified in a case study, that integrates disciplinary content, history and the nature of science along with the teaching of modeling. The proposed activity was designed for Physics teacher education students who are in the final stages of their course, but it is easily adaptable to other levels and courses. The aim of activities with teacher education students

[2] The orientation on Mathematics and Physics builds the curriculum based on modeling and, like in the orientation in Natural Sciences, there are teaching spaces on STSE and NOS.

is for them to participate as learners in some teaching activities that they are expected to employ with their own students. In the case of the activity with future teachers, once the activity is carried out, a debate is proposed on the characteristics of the resource used in teaching and its didactic use.

In the following section, we establish the framework that underpins the proposal in terms of the NOS, context, and integration of knowledge. We also outline the stance adopted for utilizing content from the history of science and we present the theoretical framework adopted for teaching based on modeling. In the third section, we describe the historical scientific controversy upon which the example activity is built, which is described below. Finally, we describe an informal and partial implementation of the activity that allowed us to identify some difficulties to be faced when carrying out this type of activity.

2 THEORETICAL FRAMEWORK

2.1 METATHEORETICAL CONTENTS, CONTEXTS, AND KNOWLEDGE INTEGRATION

The specialization and compartmentalization of science education bring with them certain difficulties that vary according to the levels and areas of teaching. One of these challenges is the effective integration of knowledge, a difficulty often expressed by students at various stages of their studies.

Focusing on the level of teacher training, this difficulty is evident in the challenges that students often face in applying knowledge learned in one disciplinary area to others. It is expected that this difficulty would be solved once they begin their professional activity, which includes guiding students in constructing the most accurate possible image of what science or a scientific discipline is.

Part of the task in teacher training institutions is to provide tools for future graduates to develop this skill. As already mentioned, it is currently accepted that scientific content encompasses not only scientific products (theories or models) but also scientific practices (methodology, resources for data collection, etc.) and the values embedded in these practices. Each of these aspects contributes to the construction of the mentioned image of science and its development process.

While some changes have occurred in recent times, traditional epistemological positions generally persist in science education. The training of teachers in Argentina has incorporated HPS and STSE content developed in the last sixty years but usually places them within the framework of isolated subjects compared to those who constitute disciplinary training.

In the teacher training institution for physics, where the didactic experience described later was informally and preliminarily implemented, compartmentalization is evident. In its curriculum, it was established that the history and epistemology of physics have differentiated curricular spaces (even separating history from epistemology), and there are no integration spaces outside those established as subjects. Workshops or forums are not planned or carried out.

It seems reasonable, and in line with new curricular designs, to advocate for a science education that incorporates the most recent HPS and STSE developments while allowing a more fluid integration of knowledge from different areas.

The introduction of historical content in science education is multifaceted and is part of the HPS content that is most frequently introduced in science classrooms. Beyond the didactic utility of certain uses of history, it is common to find biographical and authorial references to scientists and theories. However, history has multiple ways of being utilized in teaching.

As early as 1948, James Conant proposed introducing historical content in a particular way in scientific dissemination and teaching. His original purpose was to use history so that students of humanities or social sciences and those from careers not related to natural sciences could acquire a more complete idea of what science is. His argument was that taking them to a current research laboratory in Physics, Chemistry, or any other scientific discipline would not allow them to get an idea of what is done there since a very high base knowledge is needed to understand an explanation of the activities within an experimental laboratory. Therefore, if it is desired for them to have an idea of what science does, his proposal is to make them travel to past times where a research methodology such as the current one was used, but it did not require a base knowledge that exceeds that of the current high school. For this, it was necessary to introduce them to the history of science and place them in some eras where an accessible problem was discussed, and the controversies were understandable for the students [Conant, 1957].

In his book, Conant takes a series of cases from the history of physics that he selects for his objectives. Over time, new strategies for using history were developed that multiplied the alternatives. Douglas Allchin [1992] points out nine uses of history in science teaching. Among these alternatives, some use historical simulations that clearly involve using history by proposing modifications to what happened and not simply teaching a particular interpretation of historical facts. In some way, it is about inserting students into the historical context and getting them to do science with the tools of the time. After citing examples of the use of history in teaching, Allchin himself affirms the following:

> One may note, especially, that the application of history in science teaching […] involves many aims that most historians of science might not imagine in their own work. In many contexts it seems appropriate to adapt […], rework […], disguise […], distort […] or even upend […] the history itself. That is […] one may 'corrupt' the history. [Allchin, 1992]

By building upon these ideas, we can consider taking content from the history of science and using it in a more dynamic way. This approach allows us to introduce content derived from the philosophy and sociology of science, transposed didactically according to educational levels and pursued objectives. When introduced into classrooms, this not only facilitates the teaching of theories but also enables students to construct an image of science, scientists, and their activities that aligns more closely with current advancements in the philosophy of science [Paruelo, 2003; Matthews, 1992; Mellado; Carracedo, 1993; Izquierdo Aymerich; Aduriz Bravo, 2003; Gallego; Gallego, 2007].

2.2 TEACHING-BASED MODEL BUILDING

Model-based teaching is a contemporary topic of discussion with several aspects still unclear [Upmeier Zu Belzen *et al*., 2019]. Oh and Oh [2011] reviewed some of the consensuses and identified some outstanding issues while suggesting a path for model-based teaching. In their article, they propose five aspects to analyze modeling, associated with the nature of models and their uses in teaching: the meaning or characterization of "model", the purposes of the model (describe, explain, predict), the multiplicity of models (rival or competitive and noncompetitive), the change of models, and the uses of models in the classroom. Some of the mentioned characteristics coincide with current discussions in the specific field of the philosophy of science: What is a model? What role do models play in science? Why are models changed? Similarly, why is one model abandoned and another adopted? To these questions, we can add the following questions: How are different noncompetitive models articulated? [Suarez, 2003; Lombardi, 2009].

John Gilbert and Rosária Justi [2016] reviewed the characteristics of model-based teaching and modeling. In summary, the authors propose that modeling is a cycle that involves the definition of a problem, the proposal of a model to address the problem, the testing of the proposed model, and its application to the original problem as well as an analysis of other possible applications of the model. Each of these stages involves, in turn, other elements and subcycles. The definition establishes what will be the central purpose of the model and the objective pursued in its development. Testing involves successive reviews and tests until a model is achieved that meets the required parameters as a response to the problem under study. An important part of testing refers to the comparison with different proposed models with the same objective. Didactic activities for teaching modeling can address different parts of the cycle and do not need to be ordered according to the proposed cyclic sequence. This is because what is pursued with teaching activities, in the first instance, is to achieve the development of the skills required by modeling among students.

Constantinou and Papaevripidou [2019] argue that a relevant element of modeling teaching is the metascientific discussion that involves the analysis of what a model is and how it relates to theories and data. The basic idea behind teaching modeling at the middle level is to teach students to 'think' through models; that is, it is sought that students understand the models, discuss them and ultimately make their own models (of simplicity according to educational level, specificity of training, etc.), value the virtues and analyze the limits that this way of approaching problems has, in particular, scientific and technological ones. In the case of teacher training, this is crucial so that teachers can later take it to the classroom.

3 METHODOLOGY

A controversial case from science history was sought to develop an integrating teaching activity. The case to find must be one that confront at least two different models to solve a scientific or a technological problem. We take a case from history of physics to show how to develop the proposed.

3.1 THE "HORROR VACUI" VS TORRICELLI'S ATMOSPHERIC PRESSURE

There are some phenomena attributed to atmospheric pressure that before the emergence of Torricelli's theory had a different explanation. The historical context in which the discussion between Torricelli's theory and the previous explanation, based on the horror vacui, was framed was interesting for comparing two models, one that was set aside and another that proved successful.

This confrontation of models takes us back to the years of the scientific revolution of the 17th century. In his "Dialogs Concerning Two New Sciences" [2005], Galileo recounts the conversations between three characters, Simplicio, Sagredo, and Salviati, which unfold over several days in the Venetian palace of the second where the protagonists meet. Although the dialogs are the fruit of Galileo's mind, the characters were real. Salviati and Sagredo were friends of Galileo, and Simplicio was a commentator on Aristotle. In the conversations recounted in the book, Galileo puts in Simplicio's mouth the defense of Aristotelian ideas, Salviati is Galileo's spokesperson, and Sagredo is less committed in his opinions and can mediate between the arguments of the other two participants [Boido, 1996].

Currently, to contextualize the emergence of Torricelli's theory about the sea of air, a problem is often mentioned: difficulties in extracting water from wells. This is one of the issues noted by Galileo in his aforementioned text. There is an insurmountable limit of 10.33 m; beyond that height, the water does not rise without help.

The explanation available before Torricelli as to why water, or any liquid, rises along a tube, for example, by a straw in soda, was that the liquid occupied the place of the air that was removed to, in this way, prevent a vacuum from being produced in the tube. This explanation appealed to what was considered a characteristic of nature that was the so-called "horror vacui". Since Aristotle, it was held that the vacuum was impossible in the Universe and that matter came to cover any attempt to produce a vacuum. The impossibility of the vacuum works as a 'principle of nature'. By absorbing through the straw, the air is removed, which generates a vacuum that nature avoids by raising the water. A similar model explains why two well-polished plates cannot be separated when they are placed one on top of the other by removing all air bubbles between them (generating microvacuums). The vacuum that is generated between the plates causes nature to force the material that composes them to occupy it, strongly cohering the two plates. Similarly, it would also explain the cohesion between the different parts of the same material.

Usually, when Torricelli's theory is presented, it is erroneously held that it solved a problem that the 'Horror Vacui' theory could not account for: the limit of 10.33 m. An 'Aristotelian' Galileo, modifying the described model that appeals to the horror vacui [Galileo, 2005], gives an answer before that formulated by Torricelli and that he knows. What Galileo affirms allows explaining why there is a height limit for water and even allows predicting, with some convenient addition, what would happen with mercury in a tube, as Torricelli did. The hypothesis that Galileo adds can be summarized by saying that the water column behaves in the same way as a strip of any material subjected to its own weight. If a cylinder is formed with some material and is increased in length (maintaining the thickness) and placed vertically, holding it from its upper part, there will be time when the cylinder breaks. This rupture for Galileo is a product of the action of its weight against what retained it: the horror vacui. The same occurs, always according to Galileo's proposal, with a liquid in a tube. Galileo's solution was subjected to the test through an experiment carried out in Rome. They made a lead pipe of more than 10.33 meters in length in which a transparent bottle was placed at one end, carefully sealing the union of both. The pipe and bottle were filled with water and then placed vertically with the other end inside a barrel with water. The water contained in the bottle was released according to Galilean forecasts [Kuhn, 1984]. In the first of the Thalheimer lectures he gave in 1984, Kuhn states:

> The Rome experiment was performed in 1640 and word of it soon reached Galileo's pupil Torricelli. He undertook to repeat it with heavier liquids, reasoning that, if the vacuum were what supported the liquid column, all columns of given cross-section would break with the same weight, and that at lengths inversely proportional to liquids' densities. [Kuhn, p. 25]

Kuhn added that just on 1644, when he exposed his experience with mercury, Torricelli suggested that it should occur due to the weight of the atmosphere. It is then when he mentions the metaphor of the sea of air in a letter addressed to Michelangelo Ricci dated March 11, 1644.

This history shows us that both models (the Galilean horror vacui (G) and the elementary version currently taught by Torricelli (T)) account for the difficulties of extracting water from a waterhole beyond

10.33 m and allow the apparatus manufactured by Torricelli (which we now know as a barometer) to determine atmospheric pressure in the T model and the vacuum support force per unit area in the case of the G model. In one case, the weight of the liquid column balances the weight of the air column, while in the case of the G model, the weight of the liquid balances the resistance force exerted by nature to the production of vacuum, a force that has a limit equivalent to the weight of 10.33 m of water (always per unit area). We have two models with the same purpose that we can pit against each other. It is important to note that the models do not contradict each other, but simplicity or economy leads us to choose between one and the other. If we describe what each model says about what happens with a liquid when taking with a straw in a simple and vague way, we have that the G model affirms that the liquid rises because the vacuum pulls it from one side, while the T model holds that the liquid rises because the air pushes it from the other side. It is possible that the liquid rises because it is pulled from one side and pushed from the other, but simplicity leads us not to multiply causes unnecessarily.

3.2 A TEACHING ACTIVITY OF INTEGRATING MODELING

Using the previously presented models G and T, an activity was designed for advanced students in physics teaching. This activity is designed to be applied after reviewing the history of mechanics and cosmology and revisiting epistemological concepts of contrasting, articulating theories and to draw attention to the impossibility of verifying and falsifying universal hypotheses. The development of the history of mechanics and cosmology involves the analysis of the scientific revolution of the 17th century with the change from ancient science to modern science, an analysis focused on the work of Galileo Galilei in his dual role as a precursor of post-Aristotelian physics and promoter of the new way of doing science.

Given the formative stage that the students for whom the activity is proposed are going through, it is assumed that they have knowledge of classical mechanical, hydrostatic, and pneumostatic. Activity can be presented in different ways, but the goal is that students, working in groups, defend one model and challenge the other, regardless of their own convictions about which is correct. Defenses and objections have no preestablished limits, and arguments can be made from empirical data, metaphysical support, theoretical articulation, simplicity, or any other element that the participants consider useful. Subsequently, the metatheoretical discussion will be carried out by analyzing the arguments presented.

It is requested that the models be analyzed from the context that gave rise to the discussion in the 17th century; however, freedom is given for the arguments to involve later knowledge, but there is no such freedom for the use of technological resources not available at the time. At this point, it is important to note something that exceeds the objective of this article: the language used to propose the activity must be careful to avoid tilting the discussions toward one side or the other. The analysis of the language of the instructions requires specific work.

The activity consists of working with the models, proposing modifications to defend them, arguing, and experimenting as much as possible and necessary. In later classes, what has been done is discussed. In this way, future teachers train in the discussion and modification of models while working on contextualization and the teaching of the NOS in the same activity. The discussion forces one to justify why each one chooses the Torricelli model, if so, against the horror vacui and at the same time reviews why, in the history of science, that model prevailed. These arguments and counterarguments led to reviewing the differences between ancient and modern science, placing the value of empirical data in its proper place and identifying how the characteristics of science and the historical context intervene in the choice between models. A virtue of the models in dispute in this case is that their debate does not require advanced mathematical knowledge; it is enough to have knowledge of proportionality to be able to carry out the activity.

4 RESULTS AND DISCUSSIONS

An experience was made with students from de last courses to have a degree as teachers of physics and was informal because the reduced number of students. There were four of them and possibility to make groups was limited. Nonetheless, the experience carried out informally, served to identify some difficulties. One of them is how complicated it was for the students to defend the model of the horror vacui. Knowing Torricelli and even some of the students teaching it to their own students[3], they could not put themselves in the place of the defenders of the other model. However, this difficulty was also manifested in other cases, as it was not this the only activity proposed throughout the course. In another activity, a lit candle was placed in a container with water that was covered with glass. In this case, the goal is for students to look for a known model or a variant that they propose to account for what was observed [Ares *et al*., 2006]. The difficulties of proposing explanatory models or putting them up for discussion were manifested again. An interesting detail is that one of the students proposed the horror vacui to explain what happened in the experience of the candle and then realized the incompatibility of this with other accepted models. An objective of the controversial activity between models G and T is that future teachers acquire skills to argue from some model about which they are not convinced but that they can understand it, something like putting themselves in the place of what the other thinks, as a way of training in giving coherence to the models that their students can propose. A detail that caught attention was that the students did not consider the use of

[3] In Argentina there is a lack of physics teachers and so some advanced students can teach in middle school before having a degree.

experimental data, to which they could access, among their arguments. This fact may be due to many reasons that will have to be analyzed, but it is possible to propose two reasons based on the characteristics of the career plan and its implementation. One is that the career has quite differentiated the set of theoretical subjects from those where there are experimental contents, and in this case, both “History” and “Epistemology of Physics” are considered theoretical, and perhaps the students hesitate to leave those limits when arguing. The other is that the career itself, despite having experimental activities, does not place enough emphasis on the fact that experimental data are an important part of the decision to accept or reject a theory. In any case, it is a task for another investigation to see if these characteristics are repeated in a more formal implementation and, in that case, subject them to study.

5 CONCLUSION

Currently, contextualization, teaching of the NOS, and modeling constitute indispensable elements of scientific literacy and education. Graduates of a science education program must have adequate training to transfer these elements to the classroom. The design of strategies for integrating knowledge in these areas requires further development.

The review of abandoned models proves to be a useful tool for achieving these objectives. By revisiting the history of science, it is feasible to find other models in dispute that can be brought to the classroom to train teachers in testing, modifying, and arguing about models. Examples to analyze can include disputes between wave and corpuscular models of light or several that can be found in biology, such as disputes between supporters of spontaneous generation and biogenesis. The idea is to start from some dispute and use these models for debate, exercising both defense and criticism arguments where the values that count in the acceptance and rejection of models in science come into play.

The case presented in this work can be generalized for use at other levels of teaching, for example, middle school, and other formative objectives since it can be used in other careers that require scientific-technological training, considering that modeling and the use of models are present in all of them.

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