The Use of History of Science Texts in Teaching Science: Two Cases of an Innovative, Constructivist Approach

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Abstract

This study proposes an empirical classification of ways to introduce elements of the history of science into science teaching, as well as describing a special way to do so characterized by the introduction of short extracts from historical texts. The aim is to motivate students to participate in problem-solving activities and to transform their alternative conceptions about various natural phenomena. Finally, the study presents two cases of introducing the history of science into the teaching of science in Greece; the basics of Electromagnetism (primary level) and the Simple Pendulum (lower grade of secondary education).

Introduction

The use of elements of the history of science in teaching is related to, among other things, the integration into teaching of the epistemological distinction between the framework within which scientific knowledge is born and developed and the framework within which scientific knowledge is an already organized body of issues, contents, and theories (Kuhn, 1962). If the answer to the question of introducing this distinction to teaching science is affirmative, then the equally interesting question arises of the role that each one of these contexts may play in teaching. Is it absolutely necessary to make this distinction in teaching science and, if so, what is the role of the history of science (i.e., of the field that is related to the context of the birth and development of new scientific knowledge)? Answers to the above questions may be provided legitimately by areas relevant to the subject, such as Epistemology, as well as by areas related to education (e.g., pedagogy or science education).

This work explores the above-mentioned questions using methodological tools from the field of science education. First, we will propose an empirical classification of the ways of introducing elements of the history of science into science teaching in order to deal with the issue of the distinction mentioned above. Second, we will explore the features of a particular approach that we believe contributes to the functional aspect of the issue, naming this method *introducing history of science texts into science teaching*. Finally, we will describe two cases of this method of introducing elements of the history of science into teaching science, one in primary and the other in secondary education.

Ways of Introducing Elements of the History of Science Into Teaching Science

Various proposals concerning the contribution of the history of science to science teaching began to be drafted in the early 20th century (Seroglou & Koumaras, 2001). However, integration of elements of the history of science into science teaching seems to acquire a different meaning depending on the kind of transformation scientific knowledge undergoes when it becomes a school subject (school knowledge). In past studies, we have argued that, with regard to a thematic curriculum like the Greek one, it is possible to distinguish among three basic transforming categories: the traditional, the innovative, and the constructivist approaches (Koliopoulos & Constantinou, 2005; Koliopoulos & Ravanis, 2000).

In the traditional approach, elements of the history of science are either absent or introduced in a fragmented way (with biographical details of scientists, or small texts describing the results of a scientific discovery, added to the main text), without any attempt to relate with the other two dimensions of scientific knowledge; the conceptual and the methodological. In essence, it is an approach that does not accept the introduction of the framework in which scientific knowledge is born and developed into the teaching of science.

In the innovative approach to the curriculum, characterized by the formation of wider thematic and conceptual units, the "deeper" discourse of a conceptual framework and the organic enclosure of the cultural dimension of science in the various thematic units, the introduction of elements of the history of science may take various forms. One of these is the introduction of elements of the history of science as a structural principle of the curriculum. The most representative example of this is the famous Project Physics Course which appeared in the USA in the early 70s (Holton, 2003). The large-scale introduction of elements of the history of science was linked not only to an attempt to create a positive stance towards science, but also towards improving the cultural dimension of scientific knowledge (e.g., aspects of scientific knowledge related to the social context of science, through a change in philosophy of the science curriculum). However, the emergence of the framework within which new scientific knowledge is born and developed appears as an autonomous goal, without any indication of a close relationship between the historical elements and the conceptual and methodological dimensions of scientific knowledge. As Holton mentions in his book: "I had in mind that in this course a college student might take in physical science, one really must present not only good science, but also something solid on the way science is done and grows, on the scientific worldview, on how the sciences are interrelated with one another and with world history itself" (pp. 779-780). These parallel ways, the discovery framework and the explanatory framework, are also observed in the Greek version of this approach that is elucidated in the school textbook *Physics for Multisectoral Lyceum* (Dapontes, Kasetas, & Skiathitis, 1984).

The appearance of the constructivist approach[1] to the teaching and learning of science brought back the debate on the ontogenesis and phylogenesis of scientific knowledge by upgrading the role of the history of science in the exploration of the conceptual representations of students regarding natural phenomena and the concepts of science (Halbwachs, 1974; Strauss, 1988). At the same time, efforts have been made to structurally link the introduction of elements of the history of science to the conceptual and methodological dimensions of scientific knowledge (Guedj, 2005; Irwin, 2000; Raftopoulos, Kalyfommatou, & Constantinou, 2005). The introduction of conceptual models from the history of science is a characteristic example of such an approach. In this case, teaching materials deriving from the analysis of elements of the history of science can contribute to the development of teaching interventions that aim to transform students' alternative conceptions when they approach natural phenomena and the concepts that explain them. For example, Monk and Osborne (1997) suggest a teaching model for the incorporation of the history of science into science teaching where the dominant element is the comparison of ideas deriving from the history of science, students' ideas, and contemporary ideas in a thematic scientific field. The final goal is the solution of the conceptual conflicts caused by the controversies in students' thinking. Also, Seroglou, Koumaras, and Tselfes (1998) developed a research instrument with which it is possible to design teaching activities inspired by the history of science and which aims at students' cognitive progress. This instrument was applied in the cases of mechanical phenomena (with experimental activities inspired by the work of Galileo) and electromagnetic phenomena (with experimental activities inspired by the work of Gilbert and Faraday), demonstrating that students of compulsory education participating in these activities presented cognitive progress. Also, Dedes (2005a, 2005b) used material from the history of optics, and mainly the decisive experiment through which Kepler explained the optical paradox of the change in shape of the luminous print on the ground when sunlight passes through the leaves of a tree, to design teaching materials aimed at the transformation of students' conceptual representations of the rectilinear transmission of light.

The Introduction of Short Extracts From Historical Texts

One of the techniques used in the framework of this approach uses authentic or transformed historical material (mainly text) which is often linked to the so-called story-line approach. It concerns a "local" approach of the curriculum, according to which the teacher may use functional texts from the history of science as opportunities for reading and contemplation as well as for comparison or correlation. The aim here is for "the students to compare their progress in relation to the epistemological obstacles overtaken by scientists in the past" (Martinand, 1993, p. 96). In this case, an effort is made to combine the discovery framework and the explanatory framework. Stinner, MacMillan, Metz, Jilek, & Klassen (2003) suggest to teachers of all grades a methodological instrument for creating historical material that may take the form of short extracts from historical texts (vignettes) or case studies where the unifying central idea leads to the creation of stories with the use of authentic historical material. The important point in the story-line approach is that the historical material is followed by teaching situations based on the introduction and solving of problems that should interest students (Roach, 1993). One of the advantages of the creation and introduction of texts from the history of science, within the framework of the story-line approach and their localized use, is the acceptance by teachers who may use short and functional material (Monk & Osborne, 1997) and, in addition, are not obliged to form complete perceptions of the history and philosophy of science.

In the following paragraphs, we will describe the content of two cases of the use of texts from the history of science in the Greek curriculum. The first case refers to primary education and concerns the teaching of electromagnetic phenomena, while the second refers to secondary education and concerns the teaching of the simple pendulum.

The Use of Texts From the History of Science: Two Cases

Case One: The teaching of electromagnetism in the sixth grade (primary education). The entire teaching process consists of three units and has been designed to serve an innovative, as well as a constructivist, approach to the science curriculum. Before being introduced to the concepts of electromagnetism, Grade 6 students in Greece have already been taught about simple electrical circuits in the fifth and sixth grades. In the first unit, text from the history of science is introduced with the goal of creating an instructional framework for the introduction and the study of the relationship between magnetism and electricity (see Appendix A). This text functions as a problem situation in which students express their beliefs concerning this relationship. Then, the relationship between magnetism and electricity is introduced again in the form of a short text (vignette) involving Ørsted. In parallel, the students are encouraged to formulate a viewpoint of the confirmation of the phenomenological relationship between magnetism and electricity, which led to shape a version of Ørsted's experiment. The students are called upon to assess, on a metacognitive level, the ideas and views of scientists who initially addressed the existence, or non-existence, of the relationship between electricity and magnetism. The aim is for students to transform their own perceptions, which were expressed at the beginning of the teaching process.

The other two units focus on the study of the electromagnet and the electric generator, adopting a similar form of using short texts from the history of electromagnetism.

This case displays more the characteristics of an innovative approach, and especially the characteristic of the organic link between the cultural component of scientific knowledge and the other two components. The students are motivated to participate in problem-solving activities in which the social context, shaped by historical text, guides the building of knowledge. The exact opposite occurs in the traditional approach, in which the cultural component appears simply as applications of science concepts in issues of everyday life and technology. Moreover, even though this text contains no explanatory information, we claim that the proposed teaching may potentially activate mechanisms that are involved in a constructive approach to teaching, such as the mechanism of cognitive conflict. In the case of electromagnetism, this mechanism may be activated through the destabilization of the idea, on the part of the children, that there is no relationship between magnetic and electrical phenomena. A first analysis of the dialogue among students shows that the use of historical material in the form of short texts does not only contribute to the active participation of students, but also seems to help students in the process of formulating predictions and hypotheses (Stamoulis, 2005).

Case Two: The study of a simple pendulum in the ninth grade (secondary education). This case comprises a total of four units for teaching about the simple pendulum and its relation to accurate timekeeping, and serves the innovative, as well as the constructivist, approach to the science curriculum. In the traditional teaching of the pendulum, various conceptual frames are usually involved, such as Newtonian mechanics or energy conservation (Koliopoulos & Constantinou, 2005). However, in the approach suggested here, there is a deep exploration of the frame of the pendulum's isochronous movement as observed by Galileo. At the same time, there is the knowledge that, at this particular grade level, the basic conceptual problem for the students is the understanding of isochronous movement as well as the concept of the time period (Dossis & Koliopoulos, 2005). The link between the simple pendulum and the mechanisms of timekeeping enhances, on the one hand, the cultural aspect of scientific knowledge while, on the other, giving meaning to the study of the conceptual and methodological aspects of knowledge.

The foregoing rationale is served by the introduction of two short texts into teaching that include elements from the history of science. (Please see Appendices B and C for a complete schedule of activities for this case, and corresponding worksheets, respectively.) The first text refers to an extract from Galileo's book *Dialogues Concerning Two New Sciences*, and concerns the isochronous movement of the pendulum. This text is introduced in relation to problem-solving practice and aims mainly at making students discuss the paradox of the pendulum's isochronous motion; for example, a) "How do you think Salviati (the person expressing Galileo's views) would respond to the views of Sagredo?" b) "What technique would you suggest to examine whether Sagredo's claim is true or false?" In the second text, the discovery of the astronomer J. Richer is described. According to him, the length of the pendulum for counting seconds, which was set up in Paris, should have been reduced in order for the pendulum to continue to count seconds in Cayenne (Matthews, 2000). This text is related to the formulation by students of hypotheses about the factors that influence a pendulum's periods. The analysis of the discussion among students is under development (Dossis, 2005).

Conclusion

Introducing the elements of history of science, via short texts (vignettes), into the framework of the story-line approach seems to be an approach that offers multiple benefits. It is linked to ideas in the curriculum that transcend the traditional point of view in which the cultural dimension of scientific knowledge is undervalued. It seems to contribute to students' understanding of concepts and methods and to the creation of positive attitudes towards science, while also familiarizing the teacher of compulsory education with elements of the history of science. More research towards assessing this approach in relation to the cognitive and emotional progress of students and its broadening, such as its transposition to the field of teacher training, are necessary preconditions for the creation of a valid notion of the precise role that the introduction of elements of the history of science can play in teaching science.

Notes

[1]In this text, the term *constructivist* approach is used in the context of a French research tradition according to which the planning of curricula results from (a) the epistemological analysis of the content of the thematic unity to be taught, (b) the cognitive pre-instructional traits of the students that the curriculum is targeting, and (c) the features of the educational system within which the curriculum is being implemented (see, e.g., Artigues, 1988; Koliopoulos & Ravanis, 2000; Tiberghien, Psillos, & Koumaras, 1994).

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Appendix A

Worksheet for Unit 1 of Case 1: Electromagnetism

1. The following text describes a strange incident concerning the effect of a lightning storm on a boat's compasses.

> He tells me, that being once master of a ship in a voyage to Barbados, in company of another, commanded by one Crofton of New England they were, in the latitude of Bermuda, suddenly alarmed with a terrible clap of thunder, which broke this Crofton's fore-mast.
>
> By the time the noise, together with the danger of this frightful accident, was past, Mr. Howard, to whom this thunder had been more favorable, was however no less surprised, to see his companion's ship steer directly homeward again. At first he thought that perhaps the confusion, that the late mischance had put them in, might have made them mistake their course, and that they soon perceive their error. But seeing them persist in it, and being by this time almost out of call, he tacked and stood after them; and as soon as he got near enough to be well understood, asked where they were going.
>
> But their answer and by the sequel of their discourse, it at last appeared that Mr. Crofton did indeed steer by the right point of his compass, but that the needle was turned round, the North and South points having changed positions. Upon examination he found every compass on the ship in the same state. This strange and sudden accident he could impute to nothing else but the operation of the lightning or thunder newly mentioned. He adds, that he lent Crofton one of his compasses to finish the voyage; and that those thunder struck ones did never to his knowledge recover their right position again.
>
> (Source: *Philosophical Transactions*, Vol. 27, Dublin, May 10th, 1676)

What is your own explanation of what happened to the boat's compasses?

2. In 1820, while lecturing on electricity, Hans Christian Øersted connected the poles of a battery with a wire. Surprisingly, he observed that the compass dial, found on the table close to the wire, started to move from its initial position. This observation preoccupied Øersted and, later, when he was alone, he repeated the experiment many times. Later on, he wrote:

> While I prepared the presentation of an experiment, I turned to the movement of the magnetic compass needle during lighting and at the same time I supposed that an electric circuit was affecting this movement. I tried to prove it by making the following experiment. I brought the magnetic compass needle close to an electric circuit. The movement was profound, but it seemed strange and so I postponed the experiment to a later time. In July I repeated the experiments and I reached the conclusion we already know.

Try to repeat Øersted's experiment with the material available to you.

3. (a) How do you explain the movement of the magnetic compass needle?
   (b) Compare the behaviour of the magnetic compass needle when you move it close to a magnet, and then to a wire belonging to an electric circuit.
   (c) Is there any relation between electricity and magnetism?

Appendix B

Schedule of Activities for Case 2: Simple Pendulum

Schedule of activities (Teaching Unit 1)			
Actions of teacher / problem situations	Expected actions of students	Student products	Educational documents
1. Name the pieces of apparatus you have seen in the film and discuss their possible uses and usefulness.	• Name the different kinds of clocks and conclude that these are timekeeping apparatuses.		• Film concerning three kinds of clocks; the sundial, hourglass, and pendulum clock.
2. What are the similarities and differences between the three types of clocks in how they measure the duration of an event?	• Refer to the periodicity and accuracy of each type of clock..	Worksheet 1	
3. Which is the most important advantage of timekeeping with a pendulum clock over the two other types of clocks?	• Conclude that timekeeping with a pendulum clock is more accurate than timekeeping with the other types.		
4. Closing discussion.	• Recognize the necessity of accurate timekeeping.		

Schedule of activities (Teaching Unit 2)

Actions of teacher / problem situations	Expected actions of students	Student products	Educational documents
1. Discussion of the text. How do you think Salviati (i.e., the character who expresses Galileo's ideas) would go about giving a convincing answer to Sagredo's claims?	• Put forward ideas on how to confirm the isochronous movement of the pendulum.	Worksheet 2	• Historical text: Galileo and Timekeeping.
2. What specific technique would you use in order to verify Sagredo's claim?	• Propose a suitable technique to determine, through experimentation, the independence of the period of the pendulum and the amplitude of oscillation.	Worksheet 3	
3. Adoption and implementation of a technique (demonstration experiment or group work).	• Measure the period of the pendulum.		• Laboratory apparatus concerning a simple pendulum.
4. Closing discussion.	• Conclude the independence of the period of the pendulum and the amplitude of oscillation.		

Schedule of activities (Teaching Unit 3)

Actions of teacher / Problem situations	Expected actions of students	Student products	Educational documents
1. Discussion of how a simple pendulum is transformed into a pendulum clock of period 2 seconds (i.e., a single swing time of 1 second).	• Suggest the length of the string as a factor that influences the period of the pendulum.	Worksheet 4	
2. Can you propose a suitable technique to confirm, through experimentation, your assumption that the length of the string influences the period of the pendulum?	• Propose a suitable technique to control, through experimentation, the dependence of the period of the pendulum on the length of the string.	Worksheet 5	
3. Adoption and implementation of a technique (demonstration experiment or group work).	• Measure the period of the pendulum.		• Laboratory apparatus concerning the simple pendulum.
4. Closing discussion.	• Conclude that the pendulum clock with period 2 seconds (swing time 1 second) has a string length of approximately 1 meter.		

Schedule of activities (Teaching Unit 4)

Actions of teacher / problem situations	Expected actions of students	Student products	Educational documents
1. Discussion on the text. Which in your opinion is the factor that influenced the results of the measurements kept by Richer in Cayenne?	• Recognize that the pendulum clock in Cayenne is slow (i.e., its single swings take longer than 1 second). • Assume the dependence of the period of the pendulum on gravity.	Worksheet 6	• Historical text: The Voyage of Jean Richer to Cayenne. • Tracing of the trip on a desktop globe.
2. In which ways could someone confirm, or discredit, the idea that period depends on gravity? (Specifically, the greater the gravity, the smaller the period becomes.)	• Propose a suitable technique to confirm, through experimentation, the dependence of the period of the pendulum on gravity.	Worksheet 7	
3. How could this problem be resolved in those times?	• Propose the change of the length of the pendulum, or the use of a clock with timekeeping that does not depend on gravity.		
4. Which solutions would you suggest today? Closing discussion.		Homework (optional)	

Appendix C

Worksheets for Case 2: Simple Pendulum

Worksheet 1

1. What are the similarities and differences between the three types of clocks in how they measure the duration of an event?
2. Which is the most important advantage of timekeeping with a pendulum clock over the two other types of clocks?

Worksheet 2

Historical Text 1
Galileo and Timekeeping

The year 1638 was an historic one for science. Galileo published his work Dialogues Concerning Two New Sciences, one of the first written records of the birth of modern Physics. Galileo wrote this in the form of a play and discussed his ideas through its three main characters: Salviati, a brilliant scientist, who expresses Galileo's beliefs, Sagredo, a clever amateur disguised as a neutral participant, and Simplicio, the well-meaning defender of the ideas of the time. The following excerpt deals with pendulum motion (i.e., it is related to today's lesson).

> *Sagredo*: "I have observed, thousands of times, the swinging of chandeliers, especially in churches, or lamps hanging from the ceiling and moving to and fro. But the only thing I have established from these observations is that it is most unlikely that the opinion of those people who claim that all these oscillations are maintained by the environment is correct. For, if that were the case, then the wind would have to act with great insight and have nothing else to do than to give this suspended weight a perfectly regular to-and-fro motion. It is impossible for me to imagine that the same body, suspended from a string of approximately 50 meters, and moved away by 90 degrees (90^o) from its perpendicular position and then one degree (1^o) from the perpendicular position could, in both cases, take the same time to cover a very large arc and then next a very small one. That seems to me very unlikely."

How do you think Salviati, the character who expresses Galileo's ideas, would go about giving a convincing answer to Sagredo's claims?

Worksheet 3

What specific technique would you use to verify Sagredo's claim?

Worksheet 4

How could you transform a simple pendulum into a pendulum clock that takes 1 second to complete a single swing (i.e., that has a period of 2 seconds)?

Worksheet 5

Can you propose a suitable technique to control through experimentation your assumption that the length of the string influences the period of the pendulum?

Worksheet 6

Historical Text 2
An Exciting Discovery: The Voyage of Jean Richer to Cayenne

> In 1672, the astronomer Jean Richer was sent on a scientific mission by the French Academy of Sciences to the city of Cayenne, which is in French Guyana near the equator. Richer had a pendulum clock with him, which had been set in Paris to oscillate in periods of 1 second. On observing the pendulum in Cayenne, Richer made an unexpected discovery; the pendulum clock was slow by 2.5 min each day.
>
> Richer's claim that the 1-second pendulum clock slows down near the equator triggered a very interesting discussion concerning why this occurs. Some scientists doubted his measurements. In particular, Richer found himself in conflict with Huygens, the man who had constructed the clock Richer had with him.
>
> Others tried to interpret the results of these measurements. They claimed that the assumption that the period of the pendulum depends only on the length of the string is not valid. In this way, they tried to identify other factors that could influence the period, and this was in fact shown to be correct!

Which in your opinion is the factor that influenced the results obtained by Richer in Cayenne?

Worksheet 7

1. In which ways could someone confirm, or discredit, the idea that period depends on gravity (and specifically that the greater the gravity, the smaller the period becomes)?
2. How could this problem be resolved in those times?

Demonstration

Liquid Nitrogen Explosion

Needed. Liquid nitrogen, plastic soft drink bottle with cap, balloon, soft string, plastic bucket, and hot water.

Invitation. Invite students to predict what will happen when a little liquid nitrogen is placed in the plastic soft drink bottle and the opening of the balloon is stretched over the opening of the bottle.

Exploration. Try it, tying the string around the neck of the balloon to help prevent nitrogen leaking from the bottle/balloon system, and watch the balloon expand. Provided sufficient liquid nitrogen is used, the balloon will eventually explode.

Concept introduction. As the liquid nitrogen evaporates, it fills the balloon with more and more gas particles, thus increasing the pressure inside the balloon and causing the balloon to expand.

Extension. While the balloon eventually explodes, it does take quite some time to do so. Ask students to suggest a way to speed up the evaporation of the liquid nitrogen. When the idea of heating the liquid nitrogen is arrived at, try this by repeating the demonstration but this time