# Cavendish Experiment in Physics Textbooks: Why do Authors Continue to Repeat a Denounced Error?

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**Abstract**
Since long time ago, many authors advocated for more presence of physics history in physics teaching and learning in order to give students a better vision of the "nature of science", in other words, to let them learn not only established physics knowledge but also the ways of how physicists managed to get that knowledge. Generally, historical episodes are either not treated in physics textbooks (and consequently in teaching) or their treatment is reduced to a minimum: scientists' names and years. When a episode is treated with more details then some of those details are erroneous. In this article we analyze how physics textbooks authors treat one of the most famous experiments in physics history: Cavendish's determination of the density of Earth. Authors of all revised textbooks continue to repeat erroneous information, claiming that Cavendish measured the gravitational constant. As the erroneous nature of that claim for the Cavendish experiment was demonstrated many times in pedagogical and other journals, it is normal to ask: why do the authors continue to repeat it? Our hypothesis is that the "culture of teaching" is different from the "culture of research" regarding the appearance and correction of errors. We believe that only way to fight against errors in textbooks is to establish better mechanisms of veracity control, similar to those in research journals.
**Keywords**: physics textbooks, history of physics, errors, culture of teaching

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## Introduction

Idea of introducing history of science in the science curricula has been growing steadily in the last 20 years (Matthews, 1994; Brush, 1989; Irwin, 2000). These ideas were not merely declarative statements but were often supported by substantial propositions on methodic forms of historic elements that could improve science learning (Monk & Osborne, 1997; Stinner & Williams; 1998; Dagenais, 2010). There were also encouraging data showed how complex scientific themas, like atomic physics (Nussbaum, 1998) were better understood and learned when put in the context of its historical development. Along the same line, Galili and Hazan (2000), sumarize their experience gained in one optics course: Using appropriately selected historical materials that address knowledge issues relevant for the students can significantly promote meaningful learning of the subject matter (light, vision and optical images).

Generally speaking, history has been used in the physics courses, with good and not-so-good results (Solbes & Traves, 1996; Seroglou & Koumaras, 2001; Teixeira, Greca & Freire, 2009). The obstacles, which make difficult implementations of historical and philosophical aspects into physics teaching, can be structured in four groups: (1) culture of teaching physics, (2) teachers' skills, epistemological and didactical attitudes and beliefs, (3) institutional framework of science teaching, and (4) textbooks as fundamental didactical support (Höttecke & Celestino Silva, 2011).

Although "normal" physics textbooks are not good literature for appropriate introduction of history into physics teaching and learning, there are textbooks that present physical theories and concepts with abundant historical details, which might inspire and help those teachers who decide to use historical episodes as an educational resource (Cassidy, Holton &Rutherford, 2002; Holton & Brush, 2005).

Matthews (1998) set historical episodes in science on the level of philosophical issues that are better understood when looked through scientist's biographies, replicas of historical experiments, and various illustrations of scientists and their accomplishments important for the society.

Adequate methodic transformation of episodes in history of physics enables students to better understand the processes of creation, verification, and evolution of physical knowledge. In contrast, inadequate use of history potentially leads to deformation of students' ideas about nature of physics and its relation to other sciences, technology, politics, and economy.

As stated above, effects of history of physics introduction into curricula mostly depend on type of materials used and purpose of their use. During the interpolation of historical contents, it is essential to teach the students to become familiar with knowledge about scientists, events, ideas, problems, experiments, and relevant historical facts, beyond plain memorization. In his explanation of the role of history and philosophy of science in the teaching and learning process, Galili (2010) set construction of knowledge as a basic cultural aspect of every society and its individuals. Introduction of history and philosophy of science into curricula notably increases the students' ability to understand the "scientific" and create individual attitudes on science and "scientific" as a joint intellectual effort of every stakeholder involved in the process of creating knowledge through experimental and theoretical work.

In what follows we present briefly a growing research field on textbooks and a framework proposed for analyzing the use of history in them. After that we illustrate how the aim of the Cavendish experiment is formulated in recent American physics textbooks. Finally, we try to understand the presence of denounced error of attributing to Cavendish the measurement of the gravitational constant as a consequence of some basic differences between "culture of research" and "culture of teaching". We believe that the presence of physics textbook errors would be drastically reduced if teaching community and publishing industry start to apply the same mechanism of quality control already present in the "culture of research".

## Research on textbooks and a framework for analyzing the use of history

Although textbooks play an important role in science teaching and learning, scientific accuracy and cognitive adequacy of their contents were explored and analyzed much less frequently than alternative conceptions of students and teachers. In addition, there are many different views of which aspects of textbooks are worth of research efforts and interpretations.

Some authors are interested in formulating different theoretical frameworks for analyzing and improving textbooks (Stiner, 1992; Dimopulos, Koulaidis & Sklaveniti, 2005), while others pay attention to how they present nature of science (Abd-El-Khalick, Waters & Le, 2008) or how nature of science should shape textbooks (Guisasola, Almudi & Furió, 2005). There are also researchers who examine and evaluate more specific features of textbooks, like how textbooks use pictures (Stylianidou, Ormerod & Ogborn, 2002), how they treat analogies (Orgill & Bodner, 2006) or how they present scientists (Williams, 2002; van Eijck & Roth, 2008).

Nevertheless, the most popular approach is to analyze, from multiple points of view, how different textbooks deal with a particular theme, from relativity (Arriassecq & Greca, 2007) to digestion (Carvalho, Silva & Clement, 2007).

The presence of errors in science and physics textbooks is still reported from time to time, too. Discussions are mainly focused on errors related to terminology, conceptual and visual accuracy and quality of explanative arguments (Lehrman, 1982; Iona, 1987; Bauman, 1992a, 1992b, 1992c; Sawicki, 1996; Gearhart, 1996; Gauld, 1997;Entwistle at al., 1999; Santos-Benito and Gras-Marti, 2005). The errors related to the values assumed for physical quantities in numerical problems have been under scrutiny less frequently (Slisko and Krokhin, 1995, Slisko, 1995; Blickensderfer, 1998; Slisko, 2006).

More studies are also needed on historical evolution and persistence of conceptual errors. For example, such an error is the idea according to which a "total force" of a fluid, being air or water, exerted on an immersed body is obtained as a product of pressure (aerostatic or hydrostatic) and total surface of the body. This erroneous idea is present in the textbooks almost three centuries, changing its terminological and numerical forms (Slisko, 2010).

Regarding using history, obviously main issue for textbook authors and analysts is the quantity and form of historical aspects in physics that will be included (or it is included) in a textbook. Leite (2002) brought a useful framework and guide for potential authors or educators who use historical episodes in their classes. According to that framework, textbook analysis should discover how the concept of history of physics is incorporated into textbook body, considering:

- type of historical information;
- historical information organization;
- the way how historical information is used;
- accuracy of historical information;
- the context in which the historical information appear;
- connection between learning activity and history of physics;
- textbook consistency.

In addition to the characteristics mentioned above, textbook authors should also concentrate on the relation of physics and civilization in certain time and area where ideas, discoveries, experiments and postulates emerged. It is inevitable to include also technologic, religious, political, and moral information in the textbooks.

The analysis of physics textbook, as well as other fields of science requires information on modalities of presentation and handling historical data. These are:

- original documents (various manuscripts);
- photographs of scientists (personal photographs, extracts from original materials, lab documents);
- experiments and equipment;
- other materials (paintings, stamps, personal items etc.);

The choice of the consumers of historical information is also important. Historical episodes could be set out in a context useful for all pupils (compulsory part), and additionally in parts reserved for those who want to know more, or talented students. Regarding the inner consistency of historical information used in the textbook there are homogenous (same type and modality of information), and heterogeneous (several types of information) textbooks.

Methodic organization of historical episodes in physics textbooks should be considered through these three dimensions:

- historical accuracy (use of historical episodes according to original historical documents i.e. papers, letters, and notes);
- cognitive adequacy (concordance of the episode with the topic and cognitive skills of students);
- motivational potential (potential of the historical information to increase students' interest in physics).

Finally, authors should use adequate methodic transformation of stories, and other contextual information, in concordance to curricular demands.

In this article, we focus our attention on only two elements of Leite's framework: *accuracy of historical information* in textbook presentations of Cavendish experiment regarding its basic aim (what Cavendish did in his experiment?). Those who are interested in more extensive analysis of chemistry and physics textbook presentations of many other historical episodes, with an emphasis on the philosophy of science, should consult impressive work of Mansoor Niaz, recently systematized in various books (Niaz, 2008; Niaz, 2009; Niaz, 2010).

**Cavendish experiment: what are historical facts and how they are presented in physics textbooks?**

In 2009, at one international conference on physics education, during his plenary talk the first author asked the participants to answer the question: What Cavendish did in his celebrated experiment? The optional answers were:

(a) Found the mean density of the Earth;
(b) Measured the gravitational constant;
(c) Calculated the mass of the Earth;
(d) All above.

The most popular answer was (b), while the correct answer (a) was not chosen by anyone.

That situation, at first sight, might appear very strange because the essence of the Canvendish's experiment was described widely and well enough in popular books with most important writings from physics history (Magie, 1969; Shamos, 1987), in a few articles in educational journals (Clotfelter, 1987; Lally, 1999; Moreno González, 2001), in one specialized journals (Falconer, 1999), in one science education book (Lauginie, 2007) and in a recent guide on history of physics and astronomy (Heilbron, 2005).

Namely, according to these publications, historical facts about the experiment of Cavendish are:

- Cavendish DID determinate the mean density of the Earth.

- Cavendish DID NOT determinate the gravitational constant.

- Cavendish DID NOT calculate the mass of the Earth.

Important geological problem of Earth's internal structure in XVIII century was historical context in which the Cavendish experiment was designed and carried out to find a more precise mean density of our planet. That context is nicely summarized and discussed by Lauginie (2007).

Cavendish could not determinate the gravitational constant because the very idea of that constant didn't exist yet, not only in the time when Cavendish carried out the experiment but it was introduced almost a century later (Cornu & Baile, 1873; Roche, 1998; Ducheyne, 2011a;Ducheyne, 2011b).

Although, knowing the mean density of the Earth, Cavendish could calculate the mass of the Earth, he didn't calculate it because he was not interested in that number. Namely, that number *in itself* could not help geologists to infer about internal structure of the Earth.

Being so, wrong the textbooks must have influenced answers of physics teachers to the question "what did Cavendish in his famous experiment?" they use or they had read.

As it was said, historical errors related to the Cavendish experiment were denounced in pedagogical and educational journals more than once, among which were two widely known and read American journals (*American Journal of Physics* and *The Physics Teacher*). That is the reason which lead us to inspect what more recent American physics textbooks say about Cavendish experiment.

The other, not less important reason, is that American physics textbooks are used all over the world. For instance, their translations completely dominate textbook markets in Latin America, Spain and Portugal.

Here come various explicit claims about measurement (or determination or calculation) of the gravitational constant by Cavendish in very recent American physics textbooks (published starting from the year 2004, five years after the article in The Physics Teacher):

**1.** "The value for G was first measured in an experiment by the English scientist Henry Cavendish (1731 – 1810), more than a century after Newton proposed his law of universal gravitation" (Cutnell & Johnson, 2004, pp. 89-90)

**2.** "Henry Cavendish, a physicist at Oxford University in England, first measured G in 1798…" (Trefil & Hazen, 2004, pp. 98 – 99)

**3.** "The universal gravitational constant G was first measured in 1798 by Henry Cavendish… Cavendish obtained a value for G within about 1 percent of the presently accepted value.." (Tipler & Mosca, 2004, p.345)

**4.** "The value of G was first determined by Henry Cavendish in 1798…" (Fishbane, Gasiorowicz & Thornton, 2005, p. 342).

**5.** "The force between two ordinary objects was first measured by Henry Cavendish in 1798, over 100 years after Newton published his law… Because Cavendish could measure $F$, $m_1$, $m_2$, and $r$ accurately, he was able to determine the value of the constant G as well." (Giancoli, 2005, p. 119).

**6.** "The gravitational constant G… was first measured in an important experiment by Henry Cavendish in 1798." (Serway, Faugh, Vuille & Bennett, 2006, p. 207)

**7.** "It was not until 1798 (seventy-one years after Newton's death) that the value of the universal gravitational constant was experimentally determined by an English physicists, Henry Cavendish." (Wilson, Buffa & Lou, 2007, p. 232)

**8.** "To determine the value of the gravitational constant G, we have to *measure* the gravitational force between two bodies of know masses… at a known distance… The force is extremely small for bodies that are small enough to be brought into the laboratory, but it can be measured with an instrument called a *torsion balance*, which Sir Henry Cavendish used in 1798 to determine G." (Young & Freedman, 2008, p. 385)

**9.** "Interestingly, Newton could calculate the product of G and Earth's mass, but not either one alone. Calculating G alone was first done by the English physicist Henry Cavendish in 1798, a century after Newton's time." (Hewitt, 2010, p. 153).

There are also textbook authors, who attribute to Cavendish the measurement of the gravitational constant in an implicit form:

**10.** "Cavendish used the amount of twist to measure the size of the gravitational force. His results showed that the force between two 1-kilogram masses 1 meter apart would be 6.67 x $10^{-11}$ N." (Ostdiek & Bord, 2005, p. 71).

In some textbooks, among Cavendish alleged "achievements" is also the first calculation of terrestrial mass:

**11.** "For bodies of reasonable size, the force is extremely small, but it can be measured with an instrument called a torsion balance, used by Sir Henry Cavendish in 1798 to determine G…

Once Cavendish had measured G, he could compute the mass of the Earth! He described his measurement of G with grandiose phrase "weighing the earth." That's not really what he did; he certainly didn't hang our planet from a spring balance. But after he had determined G, he carried out … *calculation and determined the mass (not the weight) of the earth.*" (Young and Geller, 2007, pp. 171 – 173).

The most ironic falsification of historical facts is one in which the credit for what Cavendish really did (determination of the mean density of the Earth) is given to geologists:

**12.** "The British physicist Henry Cavendish performed an experiment in 1798 that is often referred to as "weighing the Earth". What he did, in fact, was measure the value of the universal gravitation constant, G, that appears in Newton's law of gravity…

When Cavendish measured G, he didn't actually "weigh" the Earth, of course. Instead, he calculated its mass…

> As soon as Cavendish determined the mass of the Earth, *geologists were able to use the result to calculate its average density…*" (Walker, 2007, pp. 365-366).

All these textbooks suggest wrong historical context of the experiment: (1) the idea of the gravitational constant was already introduced into the mathematical form of the law of universal gravitation and (2) the problem was to find experimentally its value.

Such a "contextualization" of the Cavendish experiment might cause that some textbook authors conclude wrongly that Newton himself introduced the idea of the gravitational constant G in the original formulation of the law of universal gravitation (Jonson, Adamson & Williams, 2001, p. 117).

Wrong information about the aim of Cavendish experiment is not the only one example, which shows that textbook authors do not consult and learn from articles published in pedagogical journals. Similar situation in university-level physics textbooks is with conceptual clarity and cognitive adequacy of themes weight, weightlessness and tides when authors present gravitation (Galili & Lehavi, 2003). While in research practice reading relevant literature (journals and books) is crucial part of the professional work, in textbook writing and likely in teaching such reading seems absent. Being so, it is necessary to look more deeply at differences between "culture of research" and "culture of teaching".

**Culture of research vs. culture of teaching**

In a recent Guest Editorial in *American Journal of Physics*, Bohren (2009) has formulated a serious accusation against scientific accuracy of physics textbooks:

> "The best advice to anyone who would write a physics textbook, especially an introductory textbook, is to adopt the working hypothesis that everything in previous textbooks is wrong."

The evidence provided by Bohren, both by the examples he discussed in text and by cited bibliography, is rather thin and unable to support his extraordinary claim. Namely, inadequate interpretations of refractive index and a few erroneous details from physics history can hardly convince anybody that everything (or almost everything) in physics textbooks has been done wrongly.

Nevertheless, Bohren rightly pointed out how one could collect a bigger collection of erroneously presented elements of physics in textbooks:

> "There is no excuse for not getting most of the physics right given the many years of publication of journals such as *American Journal of Physics, European Journal of Physics, The Physics Teacher*, and *Journal of Chemical Education*. Many papers in these journals are devoted to exposing and criticizing textbook errors."

In this article, we have shown that "exposing and criticizing textbook errors" in pedagogical and educational journal is not enough to eliminated denounced errors from the textbooks. So, we will consider the textbook errors problem in a broader context of "culture of research vs. culture of teaching".

Many informal discussions over a cap of coffee, which the first author had about physics textbook errors, reveal some naïve ideas about their origin and distributions along different educational levels.

One idea is pessimistic one: all humans err and it is impossible to think of error-free physics textbooks. The partisans of this idea forget that in all-important professions there is a permanent collective effort to get closer and closer to an (impossible) error-free performance.

The other idea is to attribute mistakes in primary and middle school science textbooks to the lack of physics knowledge of their authors. According to that view, at the university level, where physics textbook authors normally have PhD in physics, one shouldn't be able to detect too many errors.

As a PhD possession by a textbook author is by no means a guaranty of the absence of errors, a broader consideration of errors in physics textbooks would in place. In our opinion, the phenomenon of repeated mistakes is necessary consequence of a dichotomy presented in academic culture.

Since long time ago academic communities are dealing with a difficult question (Osgood, 1940; Kirkpatrick, 1959): How to reach the best possible model for making research and teaching more complementary and supportive and less competing and mutually disturbing academic activities?

The space between extreme views (academic work is basically either research or teaching) is occupied by middle-road views, which advocate a dual position, ranging from "more research for teachers" to "more teaching for researchers".

A decade ago, Rigden (1998) brought the research / teaching issue into a deserved focus, analyzing keenly some opposite characteristics of these two aspects of the academic work (Table 1**.**).

*Table 1. Dichotomies of research and teaching, according to Rigden*

| **Research** | **Teaching** |
|---|---|
| Discovery of new knowledge | Dissemination of old knowledge |
| Search of personal success | Search of success of others |
| High level of peer –reviewing | Low level of peer –reviewing |

The last dichotomy, related to the peer-reviewing, is so strong that one is tempted to start to think that in academic communities coexist, in a strange way, two cultures: the "culture of research" and the "culture of teaching". While the famous Snow's "two cultures" (*Snow, 1959*) belong to two groups of persons with completely different educational backgrounds, here paradoxically two opposite cultural patterns are revealed by persons with the same professional preparation.

When doing research in physics, they share the "culture of research", where the supreme principle is constant comparison between theoretical ideas and facts resulting from controlled experiments. When teaching they behave according to the "culture of teaching", where personal opinions and impressions about learning and teaching and results obtained by applying them are not shared with community. In that way, contrary to the "culture of research" the "theoretical ideas" about learning and teaching and results based on them are not exposed to critical considerations by others.

In such a situation, it is not a wonder that Redish (1999) asked two very disturbing questions:

> "What is it that allows us to build our knowledge of physics in a cumulative way while in physics education we seem to be doomed to everlasting cycles of pushing the Sisyphian rock up the hill only to have it roll down again?"

> "Why do we never seem to be able to share and pass down to succeeding generations what we learn about physics education?"

The only way to change that tragic situation is, of course, to try to carry out physics education as a scholar activity, discovering and defining problems and solving them in scientific fashion through a permanent dialog between theories and experiments.

Physics textbooks play important role in physics education because they bring not only what students should finally know (desired knowledge), but also ways of how to present, practice and evaluate such a knowledge. Surprisingly, as was shown above, their content was not analyzed with the same interest and rigor as were students' initial knowledge and reasoning. Some in Physics Education Research (PER) community would not accept that research on how physics knowledge is presented in textbooks forms an integral part of physics education research, forgetting that is not ethical to misinform students about any aspect of physics knowledge, being it just "unimportant" information about Cavendish experiment or, potentially more dangerous, unfeasible numbers in end-of-chapter problems and exercises (Slisko, 2006). In some professions, giving to clients an incorrect information might lead givers to a penalty and, even to jail, what would cause a serious damage of professional reputation.

It seems that textbook authors, while writing and very likely in teaching, are allowed, by a broader teaching community, not to practice the culture of research. Namely, the story about errors does not end with textbook authors. Their work is revised by many qualified reviewers and should be, in principle, evaluated critically by all those professors who recommended those textbooks to their students. If those reviewers and professors do not detect authors' errors, then the errors become "accepted truths" of the community. In that sense, the textbooks that are successful at the market, having many editions and being sold in many thousands copies, like almost all of those cited above, reflect the culture of teaching.

As many of textbook errors are not of type "only one author did only one time", it is normal to conclude that critical and creative reading and understanding of relevant published literature, so necessary for doing research, are not very common among textbook authors, reviewers and adopters.

Who works makes errors, it is sometimes said. Nobody thinks that researchers and teachers are exceptions. Nevertheless, the number of errors and the time of their presence in public professional materials is an important division line between the "culture of research" and the "culture of teaching", the first is very fast and effective in fighting them while the second is prone not even to notice them.

When an error passes through the rigorous filters of personal, group and reviewer revision processes, among readers of any specialized physics journal there will be soon a few of those who will detect the error and report it to the author or to the editor, what is an almost sure way to eliminate it. That is the reason why Errata and Rejoinder sections exist in professional journals.

## Conclusion

In the culture of research, errors committed in a published article are very adverse to the professional reputation both of researcher who wrote it and of journal in which it was published. So, it is quite unlikely for an error to live undetected for more than a year or two.

Quite contrary, the life of textbook errors in the teaching practice is much longer. Some of XIX - century errors are still present in XXI - century textbooks (Slisko, 2010). Especially disturbing case is the presence of those physics errors after they were widely denounced in pedagogical and educational journals. No profession can be considered accomplished and standing on a firm ground if the critical minds of its practitioners are sleepy and the errors, even trivial ones measured by professional standards, are more likely to stay than to go away.

We believe that some possibilities to deal with repeated errors in physics textbooks are:

(a) teaching community should pay more attention to them in research and report about them in educational journals;
(b) textbook reviewing process should be as rigorous as in research journals;
(c) important professional organizations, like American Association of Physics Teachers, American Institute of Physics, Institute of Physics (UK), European Physical Society, should try to establish standard, error-free physics knowledge suitable for teaching in form of a handbook or, even better, of an encyclopedia.

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