THE USE OF THOUGHT EXPERIMENTS IN GREEK PHYSICS TEXTBOOKS IN THE FIELD OF NEWTONIAN MECHANICS[1]

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Abstract
In the present work the use of Thought Experiments (TEs) in physics textbooks, written or translated (from English) into Greek and published during the years 1985-2005, is investigated. The study is focused on Newtonian mechanics. From the research conducted it is concluded that TEs consist an integral part of physics textbooks. The writers use them as an educational tool in order to present laws and principles of physics, especially when the understanding of the corresponding concepts requires that students overcome their every day experience.

Key-words: Thought Experiments, Physics Textbooks, Newtonian Mechanics.

1. Introduction.

Thought experiments (TEs) are experiments which are designed by scientists "without the intention of being performed" (Sorensen 1992) and consequently these experiments are performed only "in the laboratory of mind" (Brown 1991). According to Gendler (2000) performing a TE means "to reason about an imaginary scenario with the aim of confirming or disconfirming some hypothesis or theory".

TEs played an important role in the foundation of Physics' theories, especially during the scientific revolutions of the 17th and of the 20th century. They were used by famous scientists such as Galileo, Newton and Einstein whose works determined the development of Physics. According to Kuhn (1977), TEs constitute the man's dynamic tools in his effort to understand the physical world and they have played "a critically important role in the development of science". TEs are used by the scientists to criticize existing theories, to set out innovative theories, but also to argue in favor of a theory (Popper 1959/1999).

In a TE, the scientist constructs a dynamical model in his/her mind and he/she imagines a sequence of events and processes so that he/she infers the outcomes. He/she then "constructs a narrative to describe the setting and sequences in order to communicate the experiment to others" (Nersessian 1993). One of these procedures in a TE is usually abstraction. During such a procedure, one or more of the factors are conceptually eliminated, so that the impact of the remaining factors to the result of the TE is studied (Mach 1896/1976). Consequently, the setting which is "arranged" in order to "carry out" a TE refers to situations which are usually

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beyond the every day experience, whereas the performance of "experiments" requires the use of imagination as well as reasoning.

TEs, apart from being tools for scientists, also constitute important educational tools. The use of TEs in the classroom motivates students to use their imagination, develop their critical thinking, make hypotheses and draw conclusions, which are characteristics of the modern science teaching (Matthews 1994). In addition, TEs "have a long history of use in science" and "include activities" that can help students be acquainted with the scientists' practices (Gilbert & Reiner 2000).

The current study investigates the way TEs are used in physics textbooks, written or translated into Greek and published during the years 1985-2005. The study is focused on the field of Newtonian mechanics.

2. Classification of TEs.

Various classifications of TEs have been proposed for their best possible analysis. Two of these classifications are mentioned here, since they will be used in the present work.

A) According to Brown (1991), TEs are classified with respect to their use into the following categories:

(a) *Destructive TEs*: They destroy or at least pose serious problems to a theory.

(b) *Constructive TEs*: They aim at establishing a positive result and they are divided into the following sub-categories:

b1. *Meditative TEs*: They facilitate drawing a conclusion from a specific, well-articulated theory.

b2. *Conjectural TEs*: Their point is to establish some (thought- experimental) phenomenon and then they assume a theory to explain this phenomenon.

b3. *Direct TEs*: They do not start from a well articulated theory but they end with one.

(c) *Platonic TEs*: They are simultaneously destructive (a) and constructive-direct (b3)

B) According to Sorensen (1992), TEs are classified, with respect to the reasons for which they are not actually carried out, into:

(a) *Unimprovable TEs:* They are not performed in reality because "thinking about the procedure answers the question; the thought renders the action superfluous".

(b) *Unaffordable TEs:* They are not performed because "the gains are outweighed by the losses".

(c) *Impossible TEs:* Their performance is "theoretically possible but impossible in practice".

3. The school textbooks in the Greek education.

The Greek educational system, after the completion of the pre-school education, makes provision for six years of primary and six years of secondary education. For every subject, in every class, a textbook is distributed free of charge to each student by the state; the textbook is commonly used by all the Greek state school students in the country.

4. Mode of inquiry.

4.1-The sample

Five textbooks (A, B, C, D, E) were chosen as the sample of the study (Appendix). A, B, C are textbooks written by Greek authors and used in high schools during the years 1985-2005. Textbook D is the PSSC PHYSICS (Haber, at. al 1985) that was translated into Greek and was used by 1/4 of high schools in the period 1992-1997. Finally, textbook E is the CONCEPTUAL PHYSICS (Hewitt 1985). This textbook, which is translated into Greek, is available in bookshops and many teachers use it as a resource book for planning their every day lesson; however, it is not officially distributed to students.

4.2-The chapters studied

The chapters of Newtonian mechanics that were studied are:
- The *projectile motion*,
- The *laws of motion*,
- *Momentum*,
- The *law of gravity* and
- *Circular motion*.

Laws, principles and concepts referring to the above chapters are a major part of the Greek curriculum, for students at the age of 15-16 (10^{th} grade).

4.3-The Real-World Experiments and Thought Experiments found in the textbooks

All Real-World Experiments (Res), as well as all TEs, in the chapters of Newtonian mechanics of the aforementioned physics textbooks, were traced and recorded.

- We considered as REs:
  - The experiments which are meticulously described, and which can be performed in the school laboratory, in the classroom, or at home and, generally, in the students' everyday life.
  - The experiments which are difficult to be performed in the classroom, due to the fact that the required apparatus is not usually available in school laboratories (e.g. free fall in a vacuum tube), but they are described so that the necessary conclusions can be reached.
  - The experiments which are not meticulously described because the authors do not aim at performing them. Instead, their outcomes are presented (e.g. a photograph with the stroboscopic method, a table of values) so that the drawing of conclusions is possible.

In the above category references were not included, when they refer to everyday experiences of the physical world or simple accounts of everyday incidents (e.g. the driver steps on the brake and, so, the passengers move towards the front side of the bus…), as well as when they

constitute mathematical implementations of physical laws (e.g. an implementation of the principle of the conservation of momentum in the case of colliding balls).

• We considered as TEs:
All the experiments in which a physical system is described (usually one beyond the boundaries of daily experience) and then, in the context of this system, a question is posed. Furthermore, the "experimenter", based on an assumption/theory mentally predicts the facts and the procedures which will happen to the system, with the intention to answer the raised question. These facts and procedures are such that for certain reasons (e.g. technical impossibility, danger etc) it is not necessary to perform them in reality.

After recording both types of experiments, the overall percentage of the experiments which were considered as TEs, was taken, as a measure of the degree of use of TEs by the authors.

4.4-The characteristics of TEs which were investigated
In each found TE, in the specific textbooks, the following aspects were examined:

- The instructional objective of the author (e.g. formulation of a law, finding the consequences of a law etc).
- The reason for which the TE is not carried out in reality (e.g. because it is technically impossible etc).
- The existence of any corresponding historical TE and the differences of the TE as it is presented in the textbook from the description of the TE as it was found in the original text.
- The identity of the TE "experimenter" (e.g. student, famous scientist etc).
- The use of mathematical formalism.
- The use of pictures in the description of the TE and the reason that the authors used them (e.g. comprehension of text, representation of imaginary scenery etc).

4.5-The specific topic to which TEs refer
Finally, the specific topic within the syllabus (e.g. the law of inertia, conservation of momentum etc) to which the majority of TEs refer, was recorded.

5. Findings - Comments.

5.1-The percentage of use of TEs
In the table below, the percentage of the use of TEs is presented:

Textbook	Total number of REs & TEs	Number of TEs	% use of TEs
A	14	3	21.4%
B	19	3	15.8%
C	22	6	27.3%
D	15	2	13.3%
E	25	9	36%

The percentage of TEs ranges from 13.3% (in book D where the main objective is the understanding of the relative concepts by performing hands-on experiments in the school lab) to 36% (in book E where the objective is the understanding of the relative concepts without the use of mathematical formalism or complex laboratory equipment). The Greek textbooks,

according to their publishing date use TEs 21.4%, 15.8% and 27.3% respectively. The increase in the use of TEs in the newest textbook, C, is accompanied by the repeated explicit use of the term “thought experiment”. For instance, in this book (C), it is suggested: “Let us now conduct the following thought experiment…”. In other two Greek textbooks, A and B, this term never appears. Thus, it seems that in this specific textbook the role of TEs in teaching practice is recognized. An explanation of this might be that these two textbooks (A,B) were written in the beginning of the ’80s. At that period, although papers existed in the international literature, concerning the role of TEs in science, there was no research concerning their role in science education. On the other hand, when the textbook called C was written (in the end of the ’90s), research has been conducted showing the role of TEs in science teaching.

5.2 Possible reasons for the use of TEs

The authors of the textbooks use TEs for the following reasons:

a. They aim to guide students to conclusions by applying laws which have been presented in the textbook. (e.g. they apply the second Newton’s Law on a child inside in a free falling booth, and in this way, they guide students to conditions of absence of gravity in a satellite (13 out of 23 TEs or 56.5%)
b. They deduce laws, principles and, generally, make inferences, based on the results of a TE. (6 out of 23 TEs or 26%)
c. They present some problems in the context of a theory in the form of historical reference and, based on these problems, they show the way in which the new theory has been established (e.g. problems in Aristotle's theory of motion and formulation of the law of inertia). (4 out of 23 or 17.5%)

The above three uses, namely a, b and c, of the TEs, which were identified in the textbooks, correspond to the categories: Mediative-Constructive TEs, Direct- Constructive TEs και Platonic TEs, respectively, according to the classification made by Brown (1991). A clear preference of the authors to the use of TEs due to reason "a" is noticed. It is also noticed that the authors do not use Destructive TEs, as well as Conjectural TEs, like "Newton’s bucket". This finding is also the outcome of another research (Velentzas, Halkia, Skordoulis 2005a), in which we investigated the TEs included in science textbooks presenting theories of Physics in the 20th century. This might happens because for the authors of the textbooks, it appears to be instructionally useful and more efficient to focus on the theories which they want to describe than to mention the way of thinking of certain scientists who criticised the previously existing theories or developed a speculation for the consequences of these theories. That is, the authors use TEs to present some theories, but not to depict the nature of science.

5.3 The reasons for not conducting TEs

The reasons for not carrying out a TE in reality are:

(I) the performance of the "experiment" is impossible (15/23 or 65.3%) because:
- an imaginary world is required (e.g. world without frictions or gravitation)
- of the lack of appropriate technology
- the "experiment" cannot take place in the student’s every day environment (e.g. an astronaut in an orbit around the Earth).

(II) the performance of the "experiment" would be dangerous or harmful (e.g. a student in a free falling booth from a high building). (5/23 or 21.7%)

(III) the performance of the "experiment" has nothing to offer as regards the intended result. This could be achieved only by thinking (e.g. sense of gravity of an insect, which is in the bottom of a box that is rotated by a student) (3/23 or 13%)

We observe that TEs of the aforementioned categories I, II and III can be respectively tallied with the TEs' categories: "Impossible", "Unaffordable" και "Unimprovable" according to the classification made by Sorensen (1992).

5.4-The use of historical TEs

This research shows that 47.8% (11/23) of the detected TEs are based on historical TEs. Specifically, these historical TEs are:

- Galileo's TEs (Galileo 1638/1914) for the law of inertia
- "Newton's cannon" (Newton 1729/1962)
- "Einstein's elevator" (Einstein 1917/1961, Einstein and Infeld 1938)

In some cases the description of TEs is close to the description of historical TEs. In other cases the authors adapt the story and the "apparatus" of TEs to date, in order to be more attractive to students. For example, the "booth" in "Einstein's elevator" historical TE has been modified to a "spaceship". This modification is also found to a great extent in books popularizing physics theories. (Velentzas, Halkia, Skordoulis 2000a).

5.5-The identity of the "experimenter"

In studied TEs the identity of the "experimenter" who performs a TE could be that of an anonymous person (child, astronaut etc) (10/23 or 43.5%), or the student - reader (9/23 or 39.1%) or a well-known scientist (mainly in historical TEs) (4/23 or 17.4%).

5.6-The use of mathematical formalism

In the majority of TEs, the authors do not use mathematical formalism (74%). Even if it is used, it is very simple. This rather shows that TEs are useful tools in the teaching of physics, particularly in the cases where the focus is on the understanding of concepts without using mathematical formalism. This is supported by the finding that the author of textbook E uses more TEs than the authors of the other studied textbooks. The author of textbook E systematically avoids the use of mathematical formalism, whereas in the other textbooks authors make a wider use of a more academic code (formal code) as a way of presenting physics concepts.

5.7-The use of pictures

The authors of textbooks consider the use of pictures as necessary when they present TEs. In all studied TEs, authors used one or more pictures. The pictures according to their use were categorized in the following way:

- Pictures that help students imagine a scene that exceeds their experience. (12 out of 32 pictures or 37.5%)
- Pictures which refer to students' everyday experience. These are used for helping the comprehension of the text by adding auxiliary elements (e.g. an arrow that shows the direction of motion) or by showing details that cannot be "observable" with the senses (e.g. the moving projectile of a gun) (13 out of 32 pictures or 40.6%).
- Pictures, in which a person's feelings are represented. For example, a picture depicting the feelings of a girl, who is in a freely falling booth (4 out of 32 pictures or 12.5%).
- Historical pictures: pictures which were found in the original text. (3 from 32 pictures 9.4%)

5.8-Topics in which TEs are mostly used

The topics (within the syllabus) in which the writers mostly used TEs are:

- the law of inertia (5 out of 5 textbooks),
- the conditions of lack of gravity (4 out of 5 textbooks)

- the procedure of setting a body into an orbit around the Earth (3 out of 5 textbooks)

The comprehension of these subjects requires that the students construct conceptual models about the physical world, which are beyond their every day experience.

6. Conclusion.

From the present research it is concluded that:

- TEs consist an integral part of physics textbooks.
- the writers of textbooks use mainly TEs as an educational tool in order to present concepts, laws and principles of physics, the understanding of which requires that students overcome their everyday experience.
- TEs are used to a greater extent (compared to the other studied textbooks) in the textbook which uses a more familiar language (non formal code) to students, without containing particular mathematical formalism, typical scientific language or complex laboratory equipment.

The results of this research, as well as of other researches (Velentzas, Halkia, Skordoulis 2005b, Reiner, Gilbert 2000) lead to the conclusion that TEs, apart from being important tools of scientists, also constitute effective tools for the teaching of science.

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Appendix

Textbooks that were studied

TEXTBOOK A (1985-1997)
Kokkotas P., Kremmos D.,: *Fysiki A' Lykeiou (Physics for 10th grade),* O.E.D.B, Athens

TEXTBOOK B (1998-2000)
Dapontes N., Kassetas A.,: *Fysiki A' Taxi Eniaiou Lykeiou (Physics for 10th grade),* O.E.D.B, Athens

TEXTBOOK C (2001-2005)
Vlahos I., Grammatikakis I., Karapanagiotis V., Kokkotas P., Peristeropoulos P., Timotheou G.,: *Fysiki Genikis Paidias A' Eniaiou Lykeiou (Physics for 10th grade),* O.E.D.B, Athens

TEXTBOOK D (1992-1997)
Haber-Shaim U., Dodge J., Walter J.: (1992), *PSSC Fysiki,* (Translation into Greek: Kostikas A., from *PSSC Physics*-1985 Heath and Company Lexington, Massachusetts - Toronto) Idryma Evgenidou ., *Athens*

TEXTBOOK E
Hewitt, P.: (1994) Oi Ennoies tis Fysikis (*Conceptual physics),* (Translation into Greek: Sifaki E.), Panepistimiakes ekdoseis Kritis