The Use of Thought and Hands-on Experiments in Teaching Physics

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Abstract. *The history of science shows that experimentation is an important component of the work of scientists. Scientists use not only real-world experiments (REs), but also thought experiments (TEs). Likewise, in teaching physics, as it results from relative studies in textbooks, these two types of experiments are also used.*

In the present study, differences and similarities between the two types of experiments are detected, mainly according to their use, not only in the field of physics but also in the field of physics teaching so that gainful conclusions can be drawn about the possibilities of the use of both REs and TEs in physics teaching.

Keywords. Hands-on Experiments, Thought Experiments, Physics Teaching, Secondary Education.

1. Introduction

The study of history of science shows that experimentation is an important component of the work of scientists. Scientists use not only real-world experiments (REs), such as the Oersted's or Michelson-Morley's experiments, but also thought experiments (TEs), like "Newton's cannon" or "Einstein's elevator". REs are broadly used in science education. This can be found in curriculum and textbooks study. In Greece textbooks in particular are accompanied by a separate book with experiment instructions. As it results from relative studies in textbooks, TEs in addition consist an integral part of physics textbooks, even if they are used in a percentage lower than REs [1].

In the present work, an attempt was made so that differences and similarities between the two types of experiments be detected, mainly concerning their use, not only in the field of physics but also in the field of physics teaching in order that fruitful conclusions can be drawn about the possibilities of the use of both REs and TEs in the classroom.

2. REs and TEs in Physics

According to Sorensen [2], an experiment is a procedure for answering or raising a question. A TE, in contrast to a RE, achieves its aim without the need of being performed. In addition, Sorensen maintains that TEs are limiting cases of REs, that is to say, TEs evolved from REs by a process of continuous abstraction of parameters and idealization of devises and situations. For example, Galileo [3], in order to show the law of inertia, used two inclined planes. He would leave a ball move from a point of the first plane and go up to the second inclined plane. Then he would keep decreasing the angle of the second plane and observe that the ball's travelled distance was continuously increasing. In the end, Galileo, before formulated the law of inertia, he posed the question: what happens if the second plane is horizontal, completely smooth and endless? With this example it is obvious how a TE evolves from a RE with a continuous abstraction of parameters.

Miller [4], on the contrary, alleges that all experiments, REs and TEs, in the first step are created intellectually and consequently we can claim that in their initial stages all experiments are TEs. However, according to Sorensen [2], the experiments which are planned and for some reason they are not performed in reality (e.g. for financial reasons) can not be characterized as TEs. Whichever of the above views would be accepted it is resulted that there are not only differences but also similarities between the two types of experimentation. Some important differences between the two types of experimentation are [2],[5]:

(I) *TEs are planned and "performed" usually by one scientist whereas REs (especially in our days) require a team of scientists and technicians from different fields.*

According to Nersessian [6], the scientist who plans a TE constructs a mental simulation and makes inferences from it, in other words, she/he constructs a dynamic model in her/his mind and imagines a sequence of events and processes and infers outcomes. Then she/he creates a narrative

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"to describe the setting and sequence" in order to communicate the TE to others aiming at getting them to construct and run the corresponding simulation and "presumably obtain the same outcomes". Although language is used to construct that simulation, the "operations thought experimenters perform in executing the experiment are not on linguistic representations, but are on the model the narrative has enabled them to construct" [6]. So, it is possible for a person to plan and "perform" a TE. On the other hand, it is impossible that a complete RE, especially in our days, can be planned and performed only by a single person. This happens because there are many factors which should be taken into consideration that concern issues related to economics, technology, safety and collection or exchange of information etc as for example the experiments performed in CERN.

(II) *During the development and performance of a RE (and not a TE), many times, knowledge is produced not only in the field for which the RE was planed but also in other fields*. Indeed, during the solution of technical problems that appear in REs (e.g. the creation of an appropriate superconductive) a body of knowledge is produced which is not relative to the aiming result of the experiment. A characteristic example is the Internet which was created by the need of transferring experimental data and scientists' intercommunication.

(III) *Quantitative measurements are not taken during the performance of TEs* in order to complete, for example, a table of values as it happens in REs.

(IV) *TEs, in contrast to REs, do not include real apparatus and consequently we do not take into consideration (during the planning) factors which are related with attributes of materials or with questions of safety*.

(V) *During a RE, contrary to a TE, various damages or distortion of its results can happen because of unanticipated exterior factors*.

(VI) *TEs have no limitations during their "performance" which are caused by the "physical system" in which they take place, contrary to REs that cannot be implemented in any situation*. For example, a RE, contrary to a TE, cannot be performed near a black hole.

Except for the differences between REs and TEs which were referred to above, there are similarities the most important of which are [2],[5]:

(I) *Both types of experiments are used for checking physics theories aiming at their confirmation or disconfirmation*. It is usual for the scientific community to plan a RE in order to have a proposing hypothesis or theory checked. One of the most characteristic examples is the Michelson-Morley's experiment by which the hypothesis of ether was checked. However, there are cases in the history of physics that instead of a RE, a TE was used for checking a theory. For example, when Galileo [7] aimed at refuting Aristotle's allegation that the heavier body falls (in a free fall) faster than a lighter one, he invented the following TE:

Let us suppose that we have two metallic balls, the one is a cannon ball H (heavier) and the other is a pistol ball L (lighter). If the balls are released to fall from the same height (from the top of a tower), according to Aristotle's view, the ball H will move "faster" than the ball L. Then, we tie the balls with a weightless cord and we release them from the top of the tower to fall. On the one hand, based on Aristotle's allegation, the ball L acts on the ball H, because the speed of L is smaller than the speed of H, thus the system of balls moves slower than ball H. On the other hand, based on the same view, the system of balls is heavier than ball H and consequently it is faster than ball H. Obviously, it is a contradiction which is cancelled only if we accept that the balls fall simultaneously.

(II) *The results of the two types of experimentation can contribute to introduction of a new theory*. There are examples in the history of physics where the results of a RE or of a TE helped scientists introduce new theories. For example, the Oersted's experiment was critical in the introduction of the electromagnetic theory. Also, Einstein in his autobiography [8] explains a TE he thought at the age of sixteen which played an important role in the genesis of the special relativity [9]. He wondered what he would observe if he pursued a beam of light with the speed of light. It would be like running towards the shore from the end of a pier stretched out into the ocean with a wave coming in; there would be a hump on the water that is stationary with respect to the runner. However, it cannot be like that because if either the electric or the magnetic field is static it will not give rise to the other and thus there will be no electromagnetic wave.

(III) *Both REs and TEs are presented for the evaluation by the scientific community in similar ways* (e.g. conferences or journals).

3. REs and TEs in physics teaching

The experimental work in the school lab and in the classroom is an indispensable part of physics teaching and many reforms have been made in order the practical work in physics classroom to be more profitable [10]. According to Koponen and Mäntylä [10], a significant number of researchers in the field of science education put to the question the degree of effectiveness of REs in learning scientific concepts (not the gained practical skills) when experiments are used in the classroom to confirm simply what has already been taught or they have an oversimplified inductive use, as in the so-called 'discovery learning' originating in the 1960s. These researchers, who are based more or less to the theory of constructivism, agree at least with the following goals of the practical work in teaching physics: Students should have an opportunity to participate in the acquisition and construction of knowledge, see how that knowledge is reached and justified, and understand how the meaning of concepts and laws in physics is generated. In reaching these goals, students' social interaction has a crucial role. Students should have an opportunity to express their ideas in their own words, to reflect about one's own learning and correct errors, and make explicit their own intuitive reasoning. In addition, two epistemological goals need to be specified, requiring that experiments are conceived as a source of knowledge, but not only this; it needs to be recognised that experiments as a form of reasoning are conceptually comparable to theorizing [10]. These goals can be also achieved by using TEs in teaching physics. According to Reiner and Burko [11], the use of TEs in physics learning is important, because, beyond the 'elegant mental manoeuvers', it allows students 'to experience the role - supportive or destructive - of physical intuitions, incompleteness, and the importance of relevancy'. They suggest that TEs are crucial in learning, both in order to 'think physics' and in order to develop general argumentation tools, because (i) TEs help students become familiar with the culture of physics for they are inherent to physics thought, (ii) TEs, in a way, lead learners to access unspoken intuitions, knowledge both explicit and implicit, as well as help students derive logical strategies, so that they may integrate them into one working thought process, and (iii) through social discussion of TEs, thought processes and conclusions may lead to the refinement of concepts, as it happens in the physics community.

As REs and TEs in science present similarities and differences, likewise in teaching physics the above two types of experiments present similar but also different characteristic elements. For the needs of the present work it is essential that we focus mainly on the similarities and differences of the two types of experiments concerning their use, a knowledge of which (differences and similarities) may be useful for the teacher of physics. The use of TEs by authors of physics textbooks has already been studied in our two previous works [1],[12]. For the purpose of pinpointing differences and similarities concerning the use of REs and TEs (so as to cover the needs of the present work), in addition, REs that are included in two Greek textbooks of the upper secondary school and particularly in the chapters of Newtonian mechanics, relativity and quantum mechanics were studied [13],[14]. The choice of the specific areas of physics was done so that there should be a correspondence with the chapters in which TEs were studied in our previous works. From this study it results that the basic differences and similarities between REs and TEs used in teaching physics are the following:

(I) *TEs are used in contrast to REs, in cases where*:

- *there is no proper technology*,
- *the relevant RE cannot take place in the daily environment of students* (e.g. an astronaut in orbit around the Earth).
- *an imaginary world is required* (e.g. a horizontal plane with no friction with infinite dimensions or a world without gravity).
- *there is risk or material damage* (e.g. a booth with a student inside is dropped from a considerable height)
- *the implementation of the experiment has nothing to offer for the desired result*, which may be achieved only through logical reasoning (e.g. the sense of gravity of an insect at the bottom of a box rotated by a student)

(II) *REs are used, in contrast to TEs, for quantitative measurements* and specifically in cases of

- verification of quantitative laws or finding quantitative relations between physical quantities,
- finding values of physical quantities or constants, as for example the determination of the work function in the photoelectric effect, or

the measurement of Plank's constant, or the measurement of *g*.

(III) *In REs, in contrast to TEs, students*

- take measurements

- use real instruments

- take into consideration measurement errors and

- make quantitative calculations.

Apart from the above mentioned differences between the "educational" REs and TEs, there are also similarities the basic of which are the following:

(I) *Both REs and TEs are used for the introduction or the formulation of physics laws and principles*.

TEs are mainly used in textbooks in cases of teaching laws and principles of physics where it is required that students mentally transcend their every day experience, as for example the teaching of the principle of equivalence or the law of inertia or the teaching of placing a body in a steady orbit around the Earth. Also, REs are used for the introduction or formulation of physics laws and principles as for example the formulation of the second Newton's law. The use of REs in textbooks does not necessarily require students to perform the experiment; the RE may be described and its results be given for processing by students, as for example the experiment of the free fall in the vacuum tube.

(II) *Both TEs and REs are used for avoiding the use of complex mathematical formalism*.

In some cases the authors of textbooks use TEs for drawing the mathematical form of some laws, as for example the formulation of the uncertainty principle by using the TE "Heisenberg's microscope" or drawing the form of dilation of time in the special relativity by using the TE "Einstein's train" and not through the use of transformations of Lorentz. In other words, it seems that according to the authors of textbooks it is educationally more beneficial to draw a law by the help of the TE rather than by the use of purely mathematical formalism. Perhaps these authors believe that to come up with a physics law with the help of a TE, which includes narration and description of a setting composed by elements of the real world (process that according to Reiner [15] considerably decrease the use of mathematical formalism), helps students to better understand the physical meaning of the law. Also, the authors of textbooks use REs as well, for the examination of phenomena of which theoretical study demands a complex mathematical formalism, as for example the study of forced oscillations.

(III) *Both TEs and REs are used for the application of laws and principles of physics that already have been mentioned and the finding of consequences of these laws and principles*.

Both types of experimentation are used to lead students to conclusions by applying laws which they have been previously taught. For example, students apply the principle of linear momentum conservation and they explain the propulsion of rockets by performing a RE in which a balloon is propelled by taking out the air it contains, or students are led to weightless conditions by mentally performing a TE in which they apply the 2nd Newton's law to a child within a booth that falls freely.

(IV) *The prediction of results in both types of experiments helps considerably in the exploration process of student's ideas.*

It is of great value in teaching science the process through which students are asked to mentally predict the results of an experiment, whether this may take place in the school lab or not [16]. This process encourages students to express their ideas for the concepts they are about to be taught. This method, according to Mach [17], is the best for the teacher to understand the ideas and the way of thinking of his/her students. If some experiments may be done in the lab and their results are different from what students predicted during their mental performance, students will not be satisfied by their views, a fact that will considerably contribute to the conceptual change [18].

(V) *The performance not only of REs but also of TEs in the classroom should be done in groups and in collaboration.*

As already mentioned, in science TEs, in contrast to REs, are usually planned and performed by a single scientist. Yet, as research indicates [19], in the classroom not only REs but also TEs are educationally more beneficial if "performed" in collaboration.

4. Discussion

From this study it results that the two types of experimentation make it possible for their multiple uses in teaching physics and not only for the verification of already taught physics laws and theories, something which is the usual practice of traditional instruction. The use of both types of experiments in the classroom could aim at the introduction, the formulation, the verification and the application of the laws of physics that are taught. Also, both types of experiments can be used for reaching conclusions by students of the secondary education which otherwise would be difficult to be theoretically drawn because of the demand of the use of a complicated mathematical formalism.

From the already mentioned, in this work, similarities and differences between REs and TEs the teacher may draw useful conclusions for the cases in which the use of the one or of the other type of experiment is recommended. The use of TEs is recommended in cases where the performance of a RE is impossible, harmful and dangerous or has nothing to offer in the end result. TEs can also be used in the teaching of laws and principles of physics the understanding of which requires that students mentally transcend their every day experience. At this point it would be noteworthy to mention that the two types of experiments are “symbiotic”. During the performance of a RE students are also mentally experimenting [20].

In the modern teaching of physics, it is useful for students to “perform” not only REs but also TEs by working together in groups. There should also be a process of students predicting the results of the experiments so that the teacher could be aware of the students’ views as students could also be aware of their own ideas. A modern practice in teaching physics makes experimentation useful so that students are given a chance to participate in the acquisition and construction of knowledge

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