Historical Experiments in Physics Teaching*

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Is it possible to reproduce historical experiments in the classroom? The outcome of our project will be presented—We analyzed what kind of historical experiments are described in our textbooks and if students are interested in historical physics experiments. Are historical experiments really important for understanding science? The project was focused on the problem of historical experiments in teaching physics. In the textbooks, some of them are only briefly described. We studied how important it is to teach our students the history of scientific theories and understand that theories must be checked against experimental measurements. Students have to learn scientific methods in order to find out the basic principles of physics, and it can be demonstrated that the (historical) experiment is the right way of how to do it. We tested the possibility to teach and explain some topics in physics through historical experiments mostly designed with modern equipment or simple tools from everyday life. The important factor is the involvement of students themselves into this activity.

Keywords: historical experiments, physics teaching, physics textbook

Introduction

Science education cannot exist without history. The advancement in science is a never-ending story. According to Teichman (1991), history of science can play various roles in teaching physics:

1. The content of knowledge and its development;
2. Ressource of experiments, observations, and analysis;
3. The function of technology;
4. Influence of the society;
5. Historical development and students' problems and misconceptions;
6. Science today and the further development;
7. Science, technology, and society form an integrated system and it is time dependent.

History of science in schools is not a favorite topic among students. The inclusion of information about life of famous scientists and explanation of historical notes are ranked very low both on primary and secondary schools. On the other hand, practical activities needed in students' everyday life got the top ranking (Dvořák, 2008).

As shown in the research conducted by Dvořák (2008) from the range of thematic units taught in primary schools, the most interesting topics for students were: energy, sound, light, and universe. Conversely, the least interesting were considered thematic units, such as electricity and magnetism, atoms and molecules.

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From the perspective of using history in teaching physics, the best represented are thematic units: astronomy and astrophysics, optics and thermodynamics. In textbooks, we can find descriptions of series of experiments that demonstrate historical development of these scientific fields and the exploitation of discoveries, inventions, and devices in everyday life.

Molecular Physics is considered to be very attractive not only to students, but also sometimes to their teachers, because it seems to be described as too abstract, providing relatively few opportunities to demonstrate the phenomena in school practice. Therefore, it is necessary to pay more attention to this thematic unit and to demonstrate the first, second, and third laws of thermodynamics for better understanding of its content. It is also important to indicate as many examples and knowledge applications as possible. This can be achieved by inclusion of historical notes and historical experiments in the teaching process. Overcoming problems in understanding abstract Molecular Physics can be achieved through the introduction of historical notes, which reflect the historical and socio-economic background of getting knowledge and search for the possibility of their application that may improve the attractiveness, not only of this thematic unit, but also the history of physics. It is necessary to show that the background of important discoveries were people who often spent their lifetime on finding a solution to a problem and often had to fight against adversity and misunderstanding from the society.

Department of Experimental Physics in Palacký University provides History of Physics subject, but we must admit that only about 10% of all physics students attend the lectures. At the same time, the majority of our students are interested in the historical experiments and historical instruments, which is proved by their frequent visits to museums and science centers, where the interactive part of the exhibition reveals to be the most attractive for them.

The aim of our project was to study whether historical experiments can help to overcome some misconceptions in students' basic knowledge about the properties of substances of fluids, thermal physics, and thermodynamics. During the run of the project, we solved the misconception issue and also carried out an analysis of textbooks—We examined the usage of historical notes and whether they mentioned and described the historical experiments.

Students' Preconceptions

Statistical research of students' preconceptions, respectively, misconceptions focused on such issues as properties of substances, heat, temperature, energy, and their conversion took place in the Czech Republic during the years 2009-2011. There was a prepared questionnaire which was filled in by primary school students aged 10-11. In the investigation, more than 900 students from different cities and towns across the Czech Republic were involved. The research results were used in the preparation of a didactic model based on a constructive approach of teaching the theory of physics, chemistry, and biology.

One of the questions in the questionnaire concerned the issue of buoyancy and the application of Archimedes's principle. The question was formulated in the following way:

Label (circle) floating subjects and matters in the water:

(a) ferrous bullet	(e) polystyrene
(b) bullet from wood	(f) potato
(c) bullet from glass	(g) petrol
(d) cork	(h) oil

The result of statistic elaboration is shown in Table 1.

Table 1

Evaluation of the Questionnaire—Archimedes' Principle

Boys		Girls	
Classification mark 1	34%	Classification mark 1	30%
Classification mark 2	34%	Classification mark 2	27%
Classification mark 3	17%	Classification mark 3	26%
Classification mark 4, 5	15%	Classification mark 4, 5	20%

We also studied the link between the valuation and the population of the city where the respondents lived. It was found that the best results were achieved by the students living in cities that had 5,000-20,000 inhabitants. Success in a response to this question was very low, as well as in the cases of other questions in the questionnaire concerning temperature, heat transfer, and density. The results of the conducted preconceptions research were discussed by its authors (Kainzová & Holubová, 2009).

So, in our project, an attention was given in particular to the thematic unit: thermal physics, thermodynamics, and molecular physics and its elaboration in physics textbooks.

Historical Experiments in Physics Textbooks—Thermal Physics and Thermodynamics

As it was mentioned earlier (Holubová, 2013) in physics textbooks for secondary schools, we could find a description of historical experiments connected with the personality of Archimedes. His experiment concerning the proof of the authenticity of the royal crown was described and he shouted “Eureka!” when a task was solved. Archimedes's other experiments, which have practical usage, are good examples of the use of historical experiments in everyday life, for example, as the hydraulic machine press, press for olive oil, lever, Archimedes' screw, and catapult, which were not mentioned in the textbooks.

Another historical experiment that is described in physics textbooks is the steam engine. Heron's aelipila is described as an example of the first steam engine. James Watt is described as the inventor of the steam engine and the importance of this discovery for the first industrial revolution is emphasized. Steam engines are described in all physics textbooks for secondary schools. The description is accompanied by pictures, applets, and models of machines. Various types of diesel engines are described, in most textbooks, we can find in Figure 1 where there is a description of a four-stroke engine cycle.

Figure 1. Operational times of four-stroke engine (1—Suction, 2—Compression, 3—Expansion, and 4—Outlet) (Holubová, Kubínek, Richterek, & Richterková, 2011).

Most textbooks also include examples of usage in everyday life—Examples of usage in the past (steam locomotive, steam cylinder, and steamer) and today (steam turbine) (see Figure 2).

In the framework of teaching of this thematic unit, functional models of steam engines are used in a

motivational stage of the lesson or as a sample of application of knowledge in practical life, e.g., video experiment on the page of the Department of Experimental Physics workplace can be used in teaching both in secondary and high schools (For more information, please visit <http://pokusy.upol.cz/skolni-pokusy/molekulova-fyzika-a-termika/tepelne-motory/parni-stroj-43/>).

The efficiency of steam engines is discussed in the textbooks of secondary schools. In this context, the example of the steam engine is mentioned very often, which has a long history and is also being used at present—the Stirling engine. In the textbooks, there is just a small note on this machine, but we must mention that, recently, various activities related to this issue were organized, e.g., a competition called “Construct your Stirling engine” (For more information, please visit <http://fyzweb.cz/clanky/index.php?id=195>). A small picture of students’ work is shown in Figure 3.

Parní motory využívají jako pracovní látku vodní páru, což je případ zmíněného parního stroje nebo parní turbíny (obr. 117, 118).

Figure 2. Figures from a physics textbook—Steam engines (Holubova et al., 2011).

Figure 3. Examples of students’ constructions of Stirling engines.

In the chapters devoted to this issue in physics textbooks for secondary schools, there is also a featured topic of buoyancy of bodies. A number of examples from everyday life are presented—flotation glaciers, boats, and fish. It reminded submarine Nautilus from J. Verne’s (2008) novel.

A large number of phenomena in everyday life are explained by Bernoulli’s (1738) principle. However, the importance of this principle is not sufficiently emphasized and clarified even at the level of secondary school physics. Bernoulli’s work influenced the progress in mechanics and fluid mechanics and explained the

law of conservation of energy. Bernoulli also explained carburetor principle and principle of operation of the aircraft wings.

It is interesting that in physics textbooks for secondary schools in the Czech Republic, the name Daniel Bernoulli is not mentioned at all, these textbooks only provide the chapter devoted to flying. In high school physics textbooks, there is an explanation of Bernoulli's principle, but the personality of Bernoulli and his experiments from historical view are not mentioned at all. Figure 4 shows one page from a physics textbook, where the only historical note is the sentence: "Daniel Bernoulli (bernuli), 1700-1782, Swiss mathematician and physicist".

Zvětší-li se v zúžené části trubice kinetická energie E_k proudící kapaliny, zmenší se současně její tlaková potenciální energie E_p . Pro proudění ideální kapaliny ve vodorovném potrubí platí

$$E_k + E_p = \text{konst.}$$

Dosadíme-li $E_k = \frac{1}{2}mv^2 = \frac{1}{2}\rho Vv^2$ a $E_p = pV$, dostáváme

$$\frac{1}{2}\rho Vv^2 + pV = \text{konst.}$$

nebo po vydělení rovnice objemem V

$$\frac{1}{2}\rho v^2 + p = \text{konst.},$$

kde první člen rovnice představuje kinetickou energii kapaliny o jednotkovém objemu a druhý člen tlakovou potenciální energii kapaliny o jednotkovém objemu, která se současně rovná tlaku proudící kapaliny.

Součet kinetické a tlakové potenciální energie kapaliny o jednotkovém objemu je ve všech částech vodorovné trubice stejný.

Uvedená rovnice vyjadřuje zákon zachování mechanické energie pro proudění ideální kapaliny ve vodorovném potrubí. Po svém objeviteli se nazývá **Bernoulliho rovnice***. Pro vodorovnou trubici se dvěma různými průřezy je Bernoulliho rovnice

$$\frac{1}{2}\rho v_1^2 + p_1 = \frac{1}{2}\rho v_2^2 + p_2.$$

Hodnoty tlaku p_1, p_2 můžeme sledovat pomocí manometrických trubic připojených ve dvou místech vodorovného potrubí s průřezy o obsahu S_1 a S_2 (obr. 7-21). Na tlak v daném průřezu potrubí usuzujeme z výšky h kapaliny v manometrické trubici. V průřezu o obsahu S_1 je rychlost kapaliny v_1 a tlak p_1 , v průřezu o obsahu $S_2 < S_1$ je rychlost kapaliny $v_2 > v_1$, ale tlak $p_2 < p_1$. Vidíme, že v zúžené části potrubí má kapalina větší rychlost (tedy i větší kinetickou energii), ale menší tlak.

* DANIEL BERNOULLI (bernuli), 1700-1782, matematik a fyzik švýcarského původu.

Figure 4. Bernoulli equation and the mention of D. Bernoulli (Holubová et al., 2011).

Bernoulli's (1738) principle has multiple uses in our daily lives, but in high school physics textbooks, major attention is devoted to the issues of aircraft.

The Outcomes of the Project

Following the results of the survey, when the students still have misconceptions on buoyancy elements, a number of additional experiments which enable better understanding and mastering the concept were offered. If there is not enough information in the content of a textbook, we offer to complete it in the following way.

Experiment 1: Floating Bodies

1. Setting of the hypothesis—Which objects are floating on the water and which are sinking to the bottom—brainstorming and class discussion;
2. Experiments using a dynamometer;
3. Examples from everyday life—A boat made of steel floats, flotation of people, rescue of the one drowning, and fishes and their air bladders.

Competencies acquired—knowledge of the nature of buoyancy. In secondary schools, this theme is further developed—Archimedes' principle and buoyant force are discussed. It is possible to explain the principle of Archimedes' screw. In this context, we propose to use of utility “Kuličkodráha” (space-rail) (see Figure 5), which allows you to demonstrate not only a number of laws of mechanics, but also the principle of transfer of body (In this case, small balls are to be used) after racing track to its original and starter position.

Figure 5. Space-rail.

It is advantageous to use computer-aided experiments that allow you to present the issue vividly and also to change the values of the variables in phenomena. In experiments on flotation, there is an opportunity to use not only water, but also, for example, oils or other liquids (see Figure 6).

Figure 6. Measurement of buoyancy using Vernier data loggers. Retrieved from <http://www.mojewiki.cz/exploratoriumfyziky/doku.php>

Experiment 2: Bernoulli Equation

We study the flow of water from the container near its bottom. It can be shown that the speed, where g is the gravitation acceleration and h is the height of the hole above the bottom of the container.

Questions. How will the outflow of fluid, through a hole, change the height of the container? If the container height is 80 m, what is the speed at which the water will flow?

$$v = \sqrt{2gh}$$

The answer to this question is that the speed of flowing water is 40 m/s.

Discussion. In this case, Bernoulli's principle is not true obviously. Water from the reservoir in real life does not outflow with such a great speed. The main role is played by friction and the flow is turbulent. Also provided that a hole near the bottom of the container is too large, Bernoulli equation is not true.

Other possible experiments provided during the course were proved to be important to tackle students' misconceptions: (a) a ball in an air jet; and (b) a ball in a water tap.

Experiment 3: Archimedes' Principle

Let us fill a container with water up to one third; another third is filled with oil. If you pour the oil into the container very carefully, a layer will be created above the water, for the density of water is greater than the density of oil and the weight of oil is less than that of water. This phenomenon can be explained by Archimedes' principle and magnitude of a buoyant force. In our lessons, we tested the buoyancy of bodies using objects from everyday life, for example, eggs.

The questions that students asked were: 1. Will the eggs float or sink in pure water or in salt water? and 2. Is there any difference between the water is hot and cold? The students can observe that fresh eggs in clear water sink to the bottom, while in salt water, they float (you need to mix the appropriate density of the salt solution). This phenomenon is explained by Archimedes' principle: The buoyant force on a submerged object is equal to the weight of the fluid that is displaced by the object. How the body floats is determined by the density of water—If the water is too thick, just a very small part of the eggs submerged is enough to create a big enough lift force that balances the weight of the eggs.

You can also examine whether the egg is fresh, old, or spoiled (see Figure 7).

Figure 7. Exploration on flotations of eggs (The fresh egg sinks to the bottom, the old egg leans, and the rotten egg floats).

In practice, we propose to conduct experiments that are feasible without the use of complex and expensive equipment and still demonstrate these phenomena. One of such experiments is a windsock. A applicable bag's length is about eight feet and it has 10 inches in diameter. Examples of questions that students asked were: How many exhalations do we need to float a windsock? It will be 10, 20, or 30 times? We invite the students to try the experiment by themselves. Finally, we claim that the windsock can be floated by a single exhalation. It seems not doable for the students because it is a problematic situation. We show that if we hold the opening of the windsock on a distance about six inches from our mouth, it is quite possible. This experiment can be explained by Bernoulli's principle—Blowing creates a flow of air whose pressure is less than the ambient air pressure. This air is directed into the opening of the windsock. The same experiment is also described in the publication of Hewitt's *HyperPhysics*, where a motivational figure is also given (see Figure 8).

Figure 8. Windsock (Hewitt, 2001).

Thermodynamics also provides many opportunities for a technological process to be shown to the students through the history of physics and the history of experiments. We also propose to conduct experiments devoted to heat radiation, which carried out by Rumford and Leslie (1804) (as cited in Buchwald & Fox, 2013). We can indicate both the similarities of these experiments and the possibilities of their interpretation (movement of particles, respectively Caloric theory). These experiments can be continued by Joule Thomson's experiments, which are devoted to the principle of energy conservation.

Conclusions

Historical experiments and the history of physics are important ways to give students an insight into how science works. This approach allows students to achieve deeper understanding of the taught issues. History of physics, respectively, natural science is an internal part of the history of the nation as part of its cultural heritage. In addition, students' knowledge during the learning process in each grade is similar to the evolutionary processes in natural sciences.

Historical approach in teaching physics allows overcoming students' misconceptions by presenting ideas that passed through the historical developments. History of physics often suffered the the same mistakes as made by our students. From this perspective, the experiments performed by students themselves, in which they are rediscovering the laws, are the most important. In spite of that teachers often complain that experiments in education are time-consuming, and it is not possible to discuss the historical, economic, and social background of physics curriculum in the classroom, we should not ignore the importance of these experiments. It is important and necessary to incorporate historical content in teaching physics. Let us note that future generations will create the history of physics of the 21st century, as well as we create the history of physics of the 19th or 20th centuries.

Therefore, the study of the history of physics may be one of the possible ways to learn about the future. It was found that the use of history in teaching physics at primary and secondary schools has the following obstacles:

1. Lack of teachers' knowledge of the history of physics (A master's degree in teaching physics history of physics is just an optional subject);
2. Lack of time.

A current model of teaching physics is becoming gradually enriched by experiments, the descriptions of which are available for teachers and students on the Website of schools (elementary, secondary, and high). Respectively, they are also available in the annexes of current physics textbooks. In educational process, it is possible to use an empirical approach, to give examples from the history of physics during the class. It is necessary to demonstrate on what position the science has at the time when the laws were formulated and to know what are the limits of scientific knowledge. In order to implement teaching lessons with historical context, it is necessary to prepare for a teaching class in the following ways:

1. Set learning goals of the lesson;
2. Choose appropriate teaching methods;
3. Prepare interpretation in advance, including discussion of measurement precision and experimentation in the discussion period of history and at present.

Incorporation of historical experiments is possible only if the presentation is prepared in advance—Students must be instructed in advance, expectations must be raised, assumptions must be set, and observation must be conducted after the experiment. It is necessary to keep on emphasizing that scientific knowledge can not exist without observation, experimentation, and thorough theoretical training. Scientific work is always dependent on the socio-economic background in the field and at any given time.

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