Learning science through a historical approach

Aprendre ciència a través d'un enfocament històric

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abstract

Various studies have shown that a high percentage of students, whether at high school or even at college level, hold positivistic views about nature and the ways scientific investigations are carried out. The module «Science: an ever-developing entity» intends to develop an understanding of the nature of science by using historical examples, related to developments of the structure of matter and dealing with aspects of science, technology and society.

keywords

Nature of science, historical approach, aspects of science, technology and society.

resum

Diversos estudis han demostrat que un elevat percentatge d'estudiants, sigui a secundària o fins i tot a la universitat, té visions positivistes sobre la naturalesa i la manera en què es duen a terme les investigacions científiques. El mòdul «Ciència: una entitat en desenvolupament» pretén desenvolupar una comprensió de la naturalesa de la ciència utilitzant exemples històrics, relacionats amb l'evolució de l'estructura de la matèria, i tractant aspectes de la ciència, la tecnologia i la societat.

paraules clau

Naturalesa de la ciència, enfocament històric, aspectes de la ciència, tecnologia i societat.

Introduction

Many high school students finish their formal education believing that science is an enterprise by which some smart and studious people (scientists) discover the true facts of reality. Rarely is science perceived as the process by which people construct a satisfying grasp of natural phenomena, a process that involves endless testing and refining of the plausibility of their solutions. Yet, the goals of science education include all citizens understanding the process of science. As the scientific community debates these solutions, models and theories, new knowledge is developed that eventually becomes the best contemporary understanding of nature (García-Carmona & Acevedo, 2016). We want our students to understand that knowledge created by scientists is organized and continually refined and rethought and new experiments and measurements are suggested and tried. This continuous investigation and knowledge is the process known *science*; science that is appropriate for all students and necessary to be a fully functioning member of modern society.

Many students, even those who intend to become scientists, are unaware of the true nature of science (American Association for the Advancement of Science, 1989; Irwin, 1996; Duschl & Grandy, 2013). Students, both in high school and at the college level, often hold positivistic views regarding the nature of physical reality and scientific inquiries (Erduran & Dagher, 2014). While they may understand science as a systematic gathering of facts and laws, they may not be aware of the roles of science and scientists in building models and theories as tools to explain nature's laws (Hayes & Pérez, 1997). Arons (1984) claims that many science teachers under-play the scientific process and, as a result, miss opportunities to teach critical and investigative thinking. Further, they fail to emphasize that science develops culturally according to the «spirit» of each historical period, and is related to technological, political, sociological and cultural developments (Lederman, Antink & Bartos,

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2014). If science is truly to be a subject learned by all, students must perceive science as a continuously-developing product of the human mind and appreciate science as a vital program for every future citizen, including non-science majors (Hofstein, Aikenhead & Requarts, 1988; Project 2061, 1989; Gunter *et al.*, 1997).

With our goal of «Science for all», at the Weizmann Institute we developed a new module, «Science: an ever-developing entity», as part of the reform of science education in Israel (Mamlok-Naaman *et al.*, 2005). The module, which is intended for non-science majors in Israeli high schools, is designed to develop an understanding of the nature of science by using historical examples (Allchin, 2011). Science is presented as a continuously developing enterprise of the human mind illustrated by the historical development of our understanding of the structure of matter (Sparberg, 1996).

Some cognitive aspects of the historical approach

McCloskey (1983) and Hills (1992) claim that the stages in which children develop their scientific thinking parallels the stages of the historical development of science from the beginning of time. In this view, the first concepts of science that children have are similar to the concepts of scientists in the ancient times (Thagard, 1992). As ancient scientists gave human qualities to inanimate thing and described nature and natural processes in terms of emotion, so are young students building their conceptual world according to their own knowledge and feelings. Like their ancestors before them, their beliefs are based on their feelings, senses and understandings of the world around them.

For example, children can't conceive that gases have any weight, since they are invisible (Furió Mas, Pérez & Harris, 1987). Similarly, children assume that if materials are a collection of particles, then the properties of each particle, one atom, is a «piece of matter». The atomic theory, in which particles move in a vacuum and describes solid matter as mostly vacuum, was not accepted until the 17th century. It contradicted sensual perceptions and the desire for harmony (Mathews, 1994). Yet, few students (or even adults) conceive of «solid» matter as primarily empty space.

Ben-Zvi, Eylon & Silberstein (1986) note that the difficulties students face in adopting the particulate model of matter are not surprising, since it took mankind (including numerous brilliant and intuitive scholars and scientists) some two thousand years to develop and accept it. If we assume that the naïve models students bring to class are part of a normal cognitive evolution, then showing students why and how this model has changed may help them advance from their ancient and simplistic model to more modern and complex ones.

Conceptual changes are usually accompanied by cognitive as well as affective stress and difficulties. A historical approach enables us to demonstrate the development of theories and illustrates that science is an ever-developing enterprise where scientists routinely modify their ideas through logic, experiment and experience (Ben-Zvi, Eylon & Silberstein, 1988; Abd-El-Khalick & Lederman, 2000). Hall *et al.* (1983) and Holford (1985) have shown that a historical approach may help students overcome some learning difficulties while leading to a better grasp of the concepts involved.

The module «Science: an ever-developing entity»

Since the major cognitive goal of the module was to teach the nature of science (while encouraging science-alienated students to continue their study of science), we identified five principal objectives to guide our development. We wanted students completing this module to understand that:

— What sets us apart from the entire animal kingdom is our ability to ask questions about ourselves and the world around us.

— Science is a continuous, ongoing process of questioning and searching for answers, and is, therefore, part of our cultural heritage.

— The development of our understanding of the structure of matter exemplifies the main features of the scientific approach.

— There is a continuous interplay between advancing science knowledge and technological developments.

— The most essential questions remain basically the same, although the answers have changed throughout history. These changes are influenced by the available technological devices at a given period, as well as by the current social norms and pressures.

As the primary goal of the unit was to enhance students' understanding of the nature of science, we decided to design a module that systematically looked at various science concepts across time. But, having decided on the historical approach, many problems still faced us and we had to ask ourselves:

— What are the dangers of a chronological approach? What if we fail to teach many of the ideas we want to convey? What if students get bored by following the historical developments?

— Should ancient and up-to-date theories be used simultaneously to explain various phenomena? If the two are used together, will students become confused? On the other hand, if the up-to-date explanation is postponed, will the students be left with the wrong ideas?

— How should one introduce the main concepts and issues in the understanding of the structure of matter? How much background information do students need? How should we provide it without raising additional misconceptions?

At the same time, we wished to integrate issues that deal with society, economics or culture, without forgetting the main goal of the module, teaching a particular scientific topic and to what extent can one introduce the life stories of scientists without making the module too narrative.

Contents of the module

The module developed around two interwoven issues: the interrelationship between theories and experimental data, on one hand, and the links that exist between science and technology, on the other hand. Wanting to include interesting topics to motivate students while leading to our goals, we decided on two topics that seemed to be appropriate. We begin and end the module with:

— The discovery of electricity.

— Can base metals be transmuted into gold?

Fig. 1 presents the structure of the module. In the module, we trace changes in the way the question «Can base metals be transmuted into gold?» was approached and answered during our history. In doing so, we illustrate historically changes in our understanding and our current conceptions of the structure of matter. These changes across time reflect the interplay between facts and theories, as well as the interaction of culture and prevailing thought.

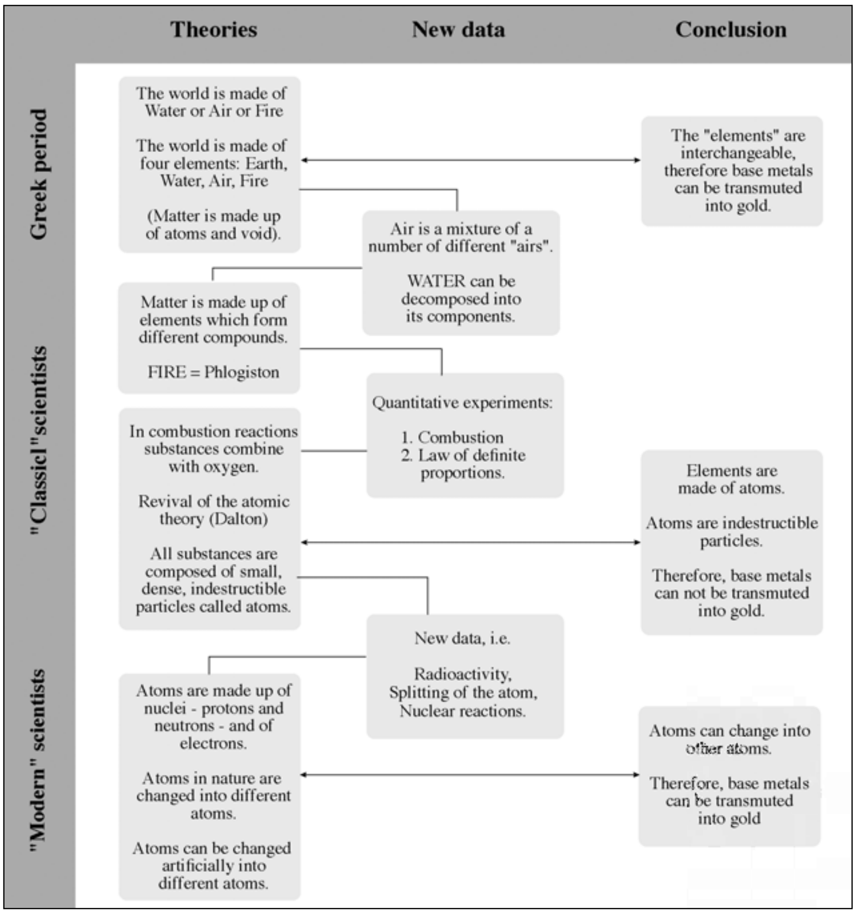

Figure 1. The structure of the module «Science: an ever-developing entity».

In the ancient Greek period, matter was conceived of as just four entities or elements: earth, water, air and fire. Each of these elements could be changed into another by performing different operations, such as heating, cooling, mixing, crystallization, etc. The natural conclusion, based on this theory, was that gold could be made from other materials provided one was clever enough to know the right transforming operations and sequence.

The Greek model survived for many centuries, until evidence and knowledge from experimentation led to contradictory conclusions. The module describes how the introduction of quantitative considerations into the chemistry laboratory brought about the revival of the atomic theory originally postulated by the Greeks. Matter, according to Dalton's 18th century views, was made up of small, indestructible particles. Dalton's atoms were the basic units of this matter, hence they could not be interchangeable. Since Dalton's theory was generally accepted, scientists (and even alchemists) concluded that one element could not be transformed into another. Thus ended the period of the ancient alchemy.

More recent experimental data, such as from natural and artificial nuclear reactions, provide a deeper understanding of the structure of matter. Atoms are no longer considered the ultimate basic particles of matter and hence elements can be changed into other elements. Can we therefore call modern physicists «the modern alchemists»? After all, we now know how to produce gold by using this method! But, though possible,

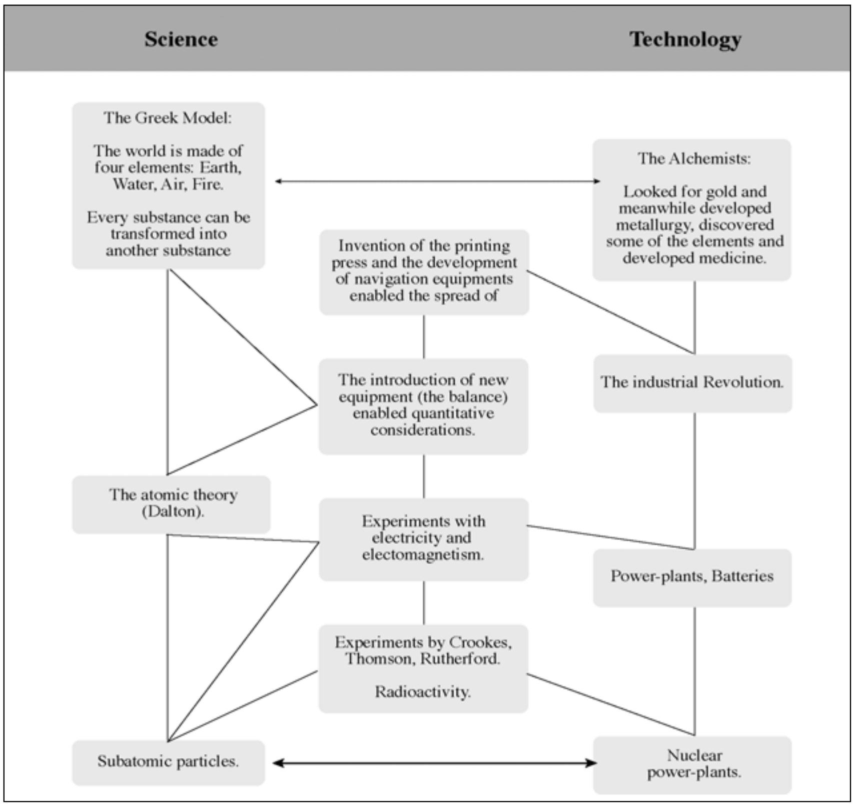

Figure 2. The relationship between science and technology.

economic calculations show that it is far cheaper to produce gold from natural ores than by using this transmutational method. Although the modern alchemists may have fulfilled the vision of the ancient alchemists, it required many years of experimentation, knowledge generation and revolutionary change in the fields of science and technology.

Fig. 2 presents the relationship between science and technology.

This representation of the process of discovery was chosen in order to show that:

— Science is not just a mere collection of facts discovered or invented randomly in the minds of scientists.

— The ancient alchemists, strange and improbable as their ideas may seem to us now, worked within the framework of their contemporary theories, just as scientists do today.

— Scientists are people who wish to understand how and why things are as they are. The outcomes of their efforts may be used for the benefit of mankind or, contrarily, as a tool for its destruction. The decision of how to use science and scientific understanding is in our hands.

This module, designed for forty class periods of 45 minutes each, uses a historical approach to emphasize links that have always existed between science and technology. In this way, students may understand how technology influenced theory and vice versa. For example, the introduction of new equipment, such as the balance, enabled quantitative considerations that led to the revival of the atomic theory. On the other hand, theoretical developments of the atomic model enabled the development of batteries and the wide use of electricity from conventional and, later, from nuclear power plants.

Field testing and evaluation

The module was field tested during one school year and then revised. Implementation and dissemination after revision was accompanied by intensive and comprehensive teacher professional development activities and evaluation studies of students and teachers.

The teachers who were involved with teaching the module had initial training in biology, chemistry or physics, and usually taught students who majored in the sciences. These teachers were not initially trained to teach interdisciplinary topics or curricula that included historical or philosophical concepts and principles. Teachers attended training activities related to the history and nature of science, as well as pedagogical techniques appropriate to this module that included collaborative study and inquiry approaches to teaching and learning. Teachers were supervised continuously by science education staff from the Weizmann Institute during the course (Cakmakci & Yalaki, 2012).

Before and during their teaching of the module, teachers attended 50 hours lectures, discussion and workshop dealing with the history and philosophy of science, instructional strategies and science concepts, and discussed the value of integrating historical aspects of science in the high school curriculum (Erduran, Aduriz-Bravo & Mamlok-Naaman, 2007). During this time, they often worked in small groups and discussed the interdisciplinary nature of content, the difficulties in coping with such topics and the required teaching methods. Relying on their rich experience as high school teachers, the teachers who participated in those workshops also prepared student supplementary materials for each chapter of «Science: an ever-developing entity». The materials developed included worksheets, lab experiments, exercises, guided reading of articles and games.

Instructional strategies used in this module include case study methods, analysis of source material, the performance of similar or identical experiments carried out at different periods, discussions and debates. During the course of study, the high school students who studied the module conducted projects, watched scientific films and analyzed relevant new scientific articles. A large part of their work was done in teams (in collaborative small groups).

Assessment of the outcomes incorporated both qualitative and quantitative methods. Qualitative analysis involved close observation of lessons, interviewing students and teachers, and describing and analyzing and disserting events. Quantitative measures assessed variables in the students' cognitive and affective domains, and allowed comparison of the experimental with the control groups. Quantitative analysis made it possible to compare achievements and attitudes before and after the teaching of science programs in the experimental and control groups.

The experimental group consisted of 10th grade students who did not choose to major in science and who studied the module, while the control group consisted of heterogeneous 10th grade students (some of them, science majors), who studied science according to the established curriculum, consisting of 3 hours of biology, chemistry and physics per week.

The analysis was conducted in two phases. A pilot study was conducted at the beginning of the academic year 1995, prior to the development of the first version of the unit. The main goal of the assessment in 1995 was to obtain information about students' interest in science, as well as their reasons for opting out of science studies. Results of the study served as guidelines in the development of the module.

Intermediate and summative evaluations were conducted during the academic years 1996 and 1997. The 1996 assessment, the first year in which the module was taught, compared the suitability of the module to the needs of the students and helped us match evaluation tools with our objectives. Following revisions based on our data and recommendations of teachers, a third version of the unit was written.

Conclusions

We hoped that teaching science from a historical point of view to high school students who do not choose to study science would affect their attitude towards science in general and scientific studies in particular, as well as their understanding about the essence of science, its development and concepts related to the structure of matter. Further, this module was designed to demonstrate the application of general ideas from the history and philosophy of science to specific topics (Matthews, 2015). The structure of matter was chosen as an example of the development of scientific thinking in terms of improved models and evolving theories. Our data indicate that students were successful at learning science concepts and finished the module with positive attitudes toward the study of science.

Based on our current level of studies with teachers using this module, we now recommended that:

— Science concepts can be taught effectively using a historical approach.

— Prior to and during the implementation of a new curriculum, teachers should be involved in preparation workshops, including development of auxiliary and learning materials, and should receive continuous support from the curriculum developers.

While not fully supported by our data, we also feel that the pedagogy used to teach a new curriculum should examine a variety of instructional methods shown by research to be effective with learning science and developing positive attitudes when working with non-science students (Mamlok-Naaman *et al.*, 2005; National Research Council, 2011).

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