

How can we motivate high school students to study science?

Rachel Mamlok-Naaman
Weizmann Institute of Science, Israel

Abstract

The main goals of this study were to find why some students in the 10th grade do not choose to major in any of the science disciplines, and how to arouse their interest in science. The assumption was that the way students perceive and evaluate their acquaintance with any kind of knowledge was very important in their learning process. If students were not interested in science, they would tend not to make an effort to learn and understand the meaning of concepts that were being taught to them. It was shown that the most effective factor contributing to students' decision to study science was their interest in the subject. We developed questionnaires, and disseminated it among 10th grade students, all between 15 and 16 years old, from three high schools located in the central part of Israel, among middle to upper socioeconomic homes. Based on the findings we concluded: (1) Despite the fact that 10th grade students studied science for three years in junior high school, many of them were unfamiliar with basic concepts that appeared in the science syllabus, and (2) the degree of interest shown by students in a given subject was greater when they were familiar with the subject and thus wished to hear and know more about it. Therefore, students' exposure to various scientific subjects can be expected to induce them to show more interest, arouse their curiosity and enhance their desire to know more. Following these results, we attempted to use a historical approach to science teaching, with the belief that it would improve the attitudes and interest of non-science-oriented students (those who did not choose to major in any of the scientific disciplines) towards science and science studies.

Key words: *Students' interest in science and in science studies; students' familiarity with scientific concepts; perceptual change; a historical approach to science teaching.*

Introduction

In this paper, we describe a study, which aims at finding out what are high school students' reasons for not choosing to major in any of the scientific disciplines, and how is it possible to motivate them to learn science. Some studies (e.g. Fraser, 1982) revealed a positive correlation and a causal relationship between achievement in science and attitude constructs, whereas others revealed no clear (or negative) relationship between attitudes towards learning science and achievement (Osborne & Dillon, 2008). International studies have shown that students' attitudes towards scientific disciplines depend on the extent of their active participation in the learning process.

Following the findings of "what are high school students' reasons for not choosing to major in any of the scientific disciplines", we attempted to use a historical approach to science teaching, with the belief that it would improve the attitudes and interest of non-science-oriented students (those who did not choose to major in any of the scientific disciplines) towards science and science studies. These findings strengthened the results of a former study, which provided guidelines for developing principles, contents, and teaching methods to a new module "Science: An Ever-Developing Entity" (Mamlok, 1995; Mamlok, Ben-Zvi, Menis, & Penick, 2000), in the framework of the program "Science and Technology for All" in Israel. Paragraphs from this module serve as intervention materials, while using the historical approach.

The module (a teaching unit) interweaves aspects of science, technology, and society, related to the development of the concept "structure of matter". It surveys the development of our understanding of the structure of matter, and attempts to develop models that can explain the accumulated observations regarding matter and chemical reactions, which is a process that is as old as science itself (another parallel subject is, for example, astronomy). Ideas concerning the structure of matter and the way models are used to explain it, which changed throughout history, constitute a good example of the representation of the history of science to students. Thus, the module was developed with the following objectives in mind: (1) to enable students who did not choose to major in any of the scientific disciplines to familiarize themselves with the nature of science, (2) to enable students to understand the interplay between science and technology, and (3) to change students' attitudes towards science in general and more specifically towards science taught in school (Mamlok-Naaman, Ben-Zvi, Hofstein, Menis, & Erduran, 2005).

As mentioned above, the main goals of this study were to find out why students do not choose to major in any of the scientific disciplines, and to arouse their interest in science by using a new module based on a historical approach.

Thus, the research questions of the study were:

- What are the reasons why students choose not to major in science?
- How can the students' continued interest in science be aroused?

Theoretical Framework

An assumption for the study was that the way students perceive and evaluate their acquaintance with any kind of knowledge is very important in their learning process (Bloom, 1976). If students are not interested in science, they tend not to make an effort to learn and understand the meaning of concepts that are being taught to them. It is shown that the most effective factor contributing to students' decision to study science is their interest in the subject (Milner, Ben-Zvi & Hofstein, 1987; Lindahl, 2003). According to Ben-Zvi and Mamlok-Naaman (2000), if we wish to evaluate students' interest in science, we must ask ourselves: Do science students gain a wide conceptual understanding of scientific concepts? And what models do students develop in order to explain natural phenomena? Justi and Gilbert (2002) claim studies show that the curriculum developers always fail in making a contribution to students' understanding of the meaning of 'model'. Erduran and Duschl (2004) extend such arguments to include the epistemological aspects of models in the classroom.

When students feel that they are familiar with concepts or issues from their former studies, and feel confident enough to explain them, it effects their motivation and achievements. Such

data is very important for the development of learning materials and for planning teaching strategies (Arzi, Ben-Zvi & Ganiel, 1986). Students, who are interested in science and understand the scientific concepts, have better attitudes towards science and science studies than those who have learning difficulties in the science disciplines. Munby (1988) claims, that an attitude mainly consists of three characteristics: feelings, cognition and behavior. According to Koballa, Crawley, & Shrigley, (1990), attitudes are feelings of “like or dislike”. Simpson & Troost (1982) referred to attitudes towards science and science learning and concluded that people are committed to science when they understand better science and desire to take more science courses, to continue reading about science. Pintrich, Marx and Boyle (1993), and Barila and Beet (1999) argue, that students' motivation is an important factor that can lead to raising or lowering the status of conception. Similarly, Fairbrother (2000) claims, that pupils learn only if they want to learn.

Based on the above, we could raise the following questions: (1) is it necessary (advisable) to teach science to all students? (2) If the answer is affirmative, should we teach all students similarly? And (3) whatever our answer to the former question, we should rethink very thoroughly how we can contribute to closing the gap between science and non-science-oriented citizens. Many researchers have answered the first question affirmatively. The American Association for the Advancement of Science (1989), for example, was concerned with the problem of how to “teach science for all Americans”. Similarly, Sjøberg (1996), presents four arguments regarding the importance of the public to understand science: (1) the economic argument: Science for preparation for work, (2) the utilitarian or practical argument: Science for mastery of daily life, (3) science for citizenship and democratic participation, and (4) science for cultural literacy, science as a major human product. Many studies focus on students' personal and societal needs and hence promoting science for responsible citizenship, a major concern in promoting student interest and motivation, especially those of girls (Holbrook, 1998; Holbrook & Rannikmae, 2007; Streller & Bolte, 2007; Yager, 2007; Bolte, 2008).

If we want to change the situation, even partially, we are immediately faced with the difficult question of how to do it. There are many problems with the way science is taught in schools, especially if we consider non-science-oriented students as our target population. The tendency, in many countries, is to give students a taste of an assortment of facts considered as important by the scientific community. Apparently, the idea behind this philosophy is the feeling that if students will have access to knowledge, their ability to cope with the modern world as well as their attitude towards science will improve. Now, it seems that this hope is not realized and the feeling nowadays favors the idea that ‘less is actually more.’ O’Neill & Polman (2004) suggest that on a societal scale, schools would function more effectively if they covered less content, in ways that would allow students to build a deeper understanding of how scientific knowledge claims and theories are constructed. This would be of use to all students in their decision-making outside of school, and beneficial to those pursuing post-secondary studies in science as well (Blonder, Mamlok-Naaman, & Hofstein, 2008).. Indeed, international studies, such as the Third International Mathematics and Science Study (Stigler & Hiebert, 1999) and the Organization for Economic Co-operation and Development (OECD/PISA/SFEG, 2004) showed that in many highly developed countries, the minimal requirement, that of acquisition of factual knowledge, is rather low.

However, the process of change is not simple, in particular for those who encounter difficulties in grasping basic scientific concepts (Nussbaum, 1989). Scientists themselves encountered difficulties in modifying their perceptions. Teaching the development of the

understanding of a concept, together with scientists' perceptions of this concept, may help to achieve a more basic and profound understanding of it and cope with any misconceptions (Matthews, 1994). The obvious conclusion of various studies is that the science curriculum must develop a historical approach to the teaching of science (Abd- El-Khalick, 2002). As a case in point, the National Science Education Standards (NRC, 1996) emphasize the fact that

In learning science, students need to understand that science reflects its history and is an ongoing, changing enterprise. The standards for the history and nature of science recommend the use of history in school science programs to clarify different aspects of scientific inquiry, the human aspects of science, and the role that science has played in the development of various cultures (p. 107).

In order to encourage a change in students' views regarding science in general and the structure of matter in particular, by studying the evolution of man's thinking and investigations, the module "Science: An Ever-Developing Entity" (Mamlok, Ben-Zvi, Menis, & Penick, 2000) was developed.

Methodology

Participants

The study began in 2000, and the participants were 10th grade students from high schools located in the central part of Israel. The group of students consisted of 90 non-science oriented students (students who chose not to major in science) in three classes – one in each school. All students were between 15 and 16 years old and came from middle to upper socioeconomic levels (60% boys and 40% girls). They studied the structure of matter using historical Interventions for 40 periods (50 minutes each) during the school year. The three teachers were experienced teachers (having more than 15 years of experience in teaching chemistry, physics, or biology for high school students).

Data Sources

Two kinds of data sources were used:

Quantitative data source - a questionnaire disseminated to the 10th grade students before studying the module. Quantitative data sources.

1. Interviews with students.
2. Observations of classroom activities.
3. Informal conversations.

All these data sources, which were originally in Hebrew, were translated into English. The translation was done by professional translators, and was critically read for validation by the author of this paper.

The questionnaire

Table 1 presents the questionnaire given to the 10th grade students. The students had to fill in this questionnaire in 45 minutes, which is one lesson period.

The objectives of the questionnaire given to the 10th grade students were to test:

1. The students' evaluation of their familiarity with scientific concepts.
2. The students' interest in science and in science studies.

Table 1. The questionnaire given to the 10th grade students (N=90)

Subject	Likert scale	No. of items
1. How do students evaluate their familiarity with scientific concepts?	1 - 4	43
2. What is students' interest in science and in science studies?	1 - 5	37

The two types of questionnaires, with different likert type scales, were used in previous studies, and already validated (Milner, Ben-Zvi & Hofstein, 1987; Mamlok, Ben-Zvi, Menis, & Penick, 2000).

How do students evaluate their familiarity with scientific concepts?

In this part of the questionnaire, students were presented with 43 scientific concepts, and they were asked to mark their degree of familiarity on the Likert Scale, on a 1 - 4 evaluation scale from “*I am not familiar at all*” to “*I am familiar and able to explain this concept to my friends*”.

The concepts were basic concepts of the structure of matter theories, such as: *air, atom, isotope, energy, atom nucleus, element, structure of water, molecule, phlogiston, proton, radioactivity, chemical reaction, theory, solution, and compound.*

The reliability (α cronbach) of this part (N=180) was 0.77.

What is the degree of students' interest in science and in science studies?

In this section of the questionnaire, students were presented with 37 scientific subjects, about which the students were asked in two sections. In one section the students were asked to indicate if they had or had not previously heard of them. In the other section, they were asked to mark their degree of interest in these subjects, even if they had never heard about them previously. Marking was done on the Likert Scale, on a 1-5 evaluation scale from “*Not interested at all*” to “*Extremely interested*”.

Here are seven scientific concepts that are related to the “structure of matter” topics and that are used to serve as examples:

- *The affect of communication on scientific developments.*
- *The development of the atom model.*
- *The link between science and technology.*
- *The development of print.*
- *Nuclear plants.*
- *The discovery of radioactivity.*
- *The particle structure of matter.*

The reliability of this part (N=175) was: (α cronbach = 0.75).

Both parts of the questionnaire were validated by 5 professionals who tested whether the statements were clear to the students and if they were as comprehensive as possible regarding the reasons for the students not selecting science studies.

Interviews

The interviews were conducted by the author of this paper at the beginning of the study and after its completion. She asked each teacher from the three classes to choose four students for the interviews. Two students were low achievers and the other two were high achievers. Each interview lasted not more than 45 minutes, and was conducted at the end of the school day. The teachers categorized their students according to their achievements in a mathematics test which was conducted at the beginning of the school year. Six students were categorized as low achievers, and a further 6 as high achievers. The interviews were semi-structured and the discussions were carried out around questions such as the following:

1. What do you do when a program that deals with a scientific issue appears on television?
2. When you read newspapers, are you interested in articles about science?
3. In your opinion, is science related to everyday life?
4. How, in your opinion, do the scientific inventions influence society?
5. What do you think is a scientists' daily routine?
6. How do you feel about studying science using a historical approach?

We are aware of the fact that questions 3 and 4 might look a little leading. However, the way in which non-science-oriented students perceive these issues was very central to this study, and unfortunately, we could not find a better way to phrase these questions.

Observations

The first author of this paper observed and videotaped three specific lessons that were given in each class, which centered around three events: (1) presenting mini-projects to all the students in the class, (2) participating in a scientific conference in school, and (3) debating on the subject: "For and against basic research" (for more details, see Appendix).

Informal conversations – The informal conversations were held by the first author of this paper with students during the breaks, and were summed up later. These discussions added insights and understanding about the students' feelings and attitudes toward learning the module "Science: An Ever-Developing Entity" (Mamlok, 1995), and served as another tool for validating the data collected from the semi-structured interviews.

Data Analysis

The data analysis is based on basic methods of quantitative and qualitative data analysis (Tobin, 1995; Glaser & Strauss, 1967). We constantly compared the data from the interview with the data from the observations, and refined them. When clarification was needed, we collected more data by informal conversations.

Analysis of the quantitative data: The questionnaire responses

Analysis of students' responses to the questionnaires given to 10th grade students was conducted by descriptive statistics: frequency calculation and t tests. The analysis refers to the question: What are 10th grade students' attitudes towards science and science studies?

The question comprised two parts:

1. Students Evaluation Relating to their Degree of Familiarity with Various Scientific Concepts

Table 2 presents the percentage of students who stated they were familiar with the given concepts and willing to explain them, and the percentage of those totally unfamiliar with these concepts (in this table the middle values - the percentage of students who were familiar with

the concept but did not understand it and those who were familiar with the concept and understood it - are not presented).

Table 2. Familiarity with Scientific Concepts (N = 90)

Concept No.	Concept	Percentage of Students Totally Unfamiliar with the Concept	Percentage of Students Familiar with and Willing to Explain the Concept
1	Air	1.1	43.6
2	Atom	3.2	23.8
3	Isotope	63.4	6.3
6	Energy	0	40.1
12	Atom nucleus	6.6	20.8
25	Element	2.1	31.7
26	Structure of water	18.3	21.0
28	Molecule	6.5	23.2
32	Phlogiston	88.1	1.6
33	Proton	15.4	14.4
36	Radioactivity	9.0	18.6
39	Chemical reaction	26.3	16.1
40	Theory	15.1	23.8
42	Solution	5.3	24.6
43	Compound	2.2	37.5

It is apparent that the majority of students claimed they were unfamiliar with concepts such as isotopes, hypothesis or phlogiston. Regarding other concepts such as element, atom or energy, only few claimed they were unfamiliar with them, but it is also evident that only a few were willing to explain them. Regarding such concepts as 'chemical reaction' it appears that approximately one quarter of all students questioned were unfamiliar with them and very few of those familiar with the concept were also willing to explain it.

It is reasonable to assume that phlogiston was not a concept they had been dealt with in their previous studies, but the other concepts appeared in the junior high school science syllabus. The majority of concepts are basic scientific concepts and findings show that most of the students do not feel they are adequately familiar with them. The conclusion was that these concepts should be combined in the module and an attempt should be made to clarify them to the utmost degree.

The Degree of Interest in Science shown by Students

Analysis of the findings was conducted in relation to students' reactions to subjects relevant to the module. Calculation of frequencies was performed according to the percentage of students who showed interest in these subjects, whether or not they had heard of them before.

It may be concluded from the findings that subjects such as: "How did communication affect scientific developments?" "Nuclear reactors", or "How did radioactivity develop?" interest students more than other subjects - over one third of the students who had heard of these subjects said they were willing to hear more. It should be noted that among the students who had not heard previously about these subjects, only 20% were interested in hearing more, i.e., after students heard about certain subjects these became more interesting and students wanted to hear more about them. This conclusion supports the basic assumption that faces all those seeking to develop syllabuses in "Science and Technology for All" - the more students are exposed to subjects in the spheres of science and technology, the more they will become

interested and involved. This was indeed one of the objectives of the module - to arouse the curiosity of students to various scientific and technological subjects and their relation to society.

Table 3. Percentage of Students who stated Familiarity with Scientific Subjects and their Degree of Interest in the Subjects (N = 90)

	I have not heard about the concept and would like to hear about it	I have heard and would like to hear more
How did communication affect scientific development?	21.2	36.8
How did the atom model develop?	22.3	21.6
The relationship between science and technology	16.1	21.1
The development of printing	14.7	14.3
Atomic reactors	19.5	35.2
How was radioactivity discovered?	19.2	37.4
The particle structure of matter	17.1	15.1

Analysis of the qualitative data

Prior to studying the module, during informal discussions with the twelve students, statements such as the followings were heard:

- “The science studies in junior high school bore me.”
- “I am not good at it.”
- “Science programs on television don’t interest me. Science studies scare me because I have to learn so many formulas.”
- “I don’t understand anything about science because I am not good in mathematics.”

Some also expressed negative attitudes towards science in general, for example:

- “It might cause disasters, like Chernobyl and Hiroshima, or may cause damage, like the hole in the ozone layer, pollution, and disease.”
- “Why does the man in the street have to invest in order to satisfy the curiosity of scientists or research institutions?”
- “Why don’t scientists concentrate on what is really needed: development of medicine to fight severe illnesses, materials to fight pollution or developing better safety mechanisms for cars to decrease the number of accidents?”

The quotations were from both low and high achievers. Interestingly, in these two diverse groups of students, we could not point out any meaningful differences regarding their attitudes towards science. Based on their statements, we concluded that the decision of many of the twelve students from the non-science-oriented classes not to continue in their science studies was influenced by their past experiences.

After the study was completed, the interviews were audio-recorded, transcribed, and analyzed according to four main categories that emerged from the teachers’ answers:

- a. Students’ attitudes towards science and science studies.
- b. Students’ perceptions of the world of the scientists.
- c. Students’ understanding of the nature of science and of technology.
- d. Students’ attitudes towards studying science using a historical approach.

We will elaborate on each of the categories that emerged after analyzing the data from the three sources of data.

a. Students' attitudes towards science and science studies

The students' initial negative attitude towards science and science studies seemed to have undergone a gradual change during the period of study. Some of them began to show interest in the phenomena around them, exemplified by their reading science sections in the daily newspapers and watching science programs on television. In addition, they brought interesting articles from the newspapers and shared them with their colleagues. During one of the interviews, a low achieving student remarked: "I don't turn off the television anymore when I happen to see a program devoted to a scientific subject."

Most students claimed that they had a negative attitude towards science studies because they were afraid that they would be unable to cope with formulas or with mathematical computation. Therefore, studying the module changed their attitude toward science studies and reduced their anxiety. They also claimed that the method used which provided them with a good understanding and an overall perspective of the subject, made them like it and in fact enhanced their interest. This can be exemplified by the words of another low achiever:

I used to hate science studies because I was afraid of the formulas and didn't understand what they wanted from me. In this year's program very few formulas were included and we learned to understand phenomena without becoming entangled in calculations. Personally, I stopped being afraid of science and even enjoyed myself.

Almost all the students expressed their satisfaction with the variety of teaching strategies. After preparing mini-projects and presenting them to their peers, both in class and at a scientific conference in school, the students were extremely proud of their work and of the fact that their projects were presented together with other students – students who chose to major in science.

b. Students' perceptions of the world of the scientists

Before they studied the module, most of the students did not have a realistic picture of science and of scientists. For example, a third low achiever said:

I always thought that names like Aristotle or Galileo or Newton are names of weird and strange people who lived in a strange world. Now I know that they are people just like us, only very curious and persistent.

As mentioned, one of the activities accompanying the unit was a group activity where each student had to prepare a mini-project and present it to his peers. The topics were, among others, simulations of an argument between: (a) Lavoisier, Priestley, and Cavendish about the oxygen vs. the phlogiston theories, (b) Galileo and Aristotle concerning the nature of a scientific theory, (c) the alchemists and (d) the work of Newton. Exposure to these activities seemed to have broadened students' horizons.

Summary

According to the findings of the study it may be concluded that many students of the 10th grade students are unfamiliar with basic concepts that appear in the science syllabus (such as

hypothesis, isotopes), despite that fact that they studied science in junior high school. In relation to other more familiar concepts (such as atom, element, energy), not all of the students were willing to explain them. Since these are basic scientific concepts and the "Science: An Ever-Developing Entity" module's (in the "Science and Technology for All" syllabus) main objective was to inculcate scientific knowledge, these concepts, therefore, are combined in the module in a way which will be clear to the students, arouse their interest and enhance their understanding of their use. The hypothesis was that learning these concepts through an historical approach, the way in which they were comprehended over the years, combined with the historical events related to the development of the structure of matter will help in achieving this objective.

An additional conclusion was that the degree of interest shown by students in a given subject is greater when they are familiar with the subject and thus wish to hear and know more about it. Therefore, students' exposure to various scientific subjects may induce them to show more interest, arouse their curiosity and enhance their desire to know more. Subjects with which they are familiar should be developed in order to continue to arouse their interest. A method should be found to present other subjects, unfamiliar to them, but central to science and important to every person's general education. Perhaps they may be asked in the future to relate to and make decisions based on them. If they are unfamiliar with these subjects how will they be able to form their opinion? How will they know whether they will use them or not? It may be assumed that subjects such as "The relationship between Science and Technology" or "How did the Model of the Atom Develop?", which only a few students stated they had heard of before, or were interested in (approximately 20%) will arouse student interest if these are presented as basic subjects for the understanding of environmental phenomena which affect our lives, while emphasizing their relation to everyday life and our times and society. Indeed, the majority of 11th grade students who did not choose to study science indicated an interest in subjects that are closely related to their bodies and environment (the human body and the Earth's sciences). Scientific development, the uses of science, the energy crisis - these subjects were distant to them and students were unaware of their importance. What was their contribution? Why should their study be desirable? Will they help them to solve problems? Had these students, who did not choose to study science, studied the importance of these subjects and their contribution to their education and the development of society, they might have shown greater interest and might even have modified their attitudes towards science studies.

The interest of 11th grade students, who chose the social sciences and humanities, and their desire to become involved in these spheres in the future, was their main reason for not choosing any of the science disciplines. We can conclude that integrating historical and social aspects in the science curriculum may encourage students to become interested in these syllabuses and acquire scientific knowledge.

In summary: the findings of the study are compatible with previous studies conducted in Israel on this subject, with students who chose science studies (Milner et al., 1987). These findings helped in forming the guidelines for developing principles, contents, and teaching methods to the "Science: An-Ever Developing Entity" module.

- The concepts which appear in the module should be explained through the development of the way they were grasped and understood by scientists in various periods in order to try and clarify them for students by a different method of study.

- Scientific events and developments should be integrated into technological and social developments in order to underscore the fact that science is part of human's everyday life in each period.
- The development of a scientific theory and model should be done through the work of scientists in the framework of the scientific community and the specific period. Basic research versus applied research - all these are combined in each of the chapters.

The process of perceptual change is not simple, in particular for those who encounter difficulties in grasping basic scientific concepts (Nussbaum, 1998). Scientists themselves encountered difficulties in modifying their perceptions. Teaching the development of the understanding of a concept, together with scientists' perceptions of this concept, may help to achieve a more basic and profound understanding of it and cope with misconceptions (Nussbaum, 1990; Matthews, 1994).

Some researchers have presented the idea that students' initial scientific knowledge is analogous to the knowledge of scientists in the ancient world, and is made up of observations and conclusions, which were often intuitive (Thagard, 1992; Irwin, 1997; Erduran, 2003). Just as these scientists tended to personify objects, or describe processes and natural phenomena in emotional terms, so do children build a conceptual world which is adjusted to their own world of knowledge and emotions. They believe in what they sense and tend not to believe in what is out of the scope of their senses. Thus, the suggestion of some researchers is that science curriculum should develop a historical approach to the teaching of science (Erduran, 2001; Abd-El-Khalick, 2002).

However, the process of change is not simple, in particular for those who encounter difficulties in grasping basic scientific concepts (Nussbaum, 1989). Scientists themselves encountered difficulties in modifying their perceptions. Teaching the development of the understanding of a concept, together with scientists' perceptions of this concept, may help to achieve a more basic and profound understanding of it and cope with any misconceptions (Matthews, 1994). The obvious conclusion of various studies is that the science curriculum must develop a historical approach to the teaching of science (Abd- El-Khalick, 2002).

References

- American Association for the Advancement of Science. (1989). *Science for all Americans: A Project 2061 report on literacy goals in science, mathematics and technology*. Washington, DC: Oxford University Press.
- Abd-El-Khalick, F. (2002). Rutherford's enlarged: A content-embedded activity to teach about the nature of science. *Physics Education*, 37, 64-68.
- Arzi, H., Ben-Zvi, R., & Ganiel, U. (1986). Forgetting versus Savings: The Many Facets of Long-Term Retention. *Science Education*, 70, 171-88.
- Barila, L., & Beeth, M. E. (1999). *High school students' motivation to engage in conceptual change learning in science*. Paper presented at the Annual Meeting of the National Association for Research in Science Teaching, Boston, MA.
- Ben-Zvi, R., & Mamlok-Naaman R (2000) Is there a link between curriculum content and students understanding of the concept of energy? In: Paper presented at the Annual Meeting of the National Association for Research in Science Education, New Orleans, LA
- Bloom, B. (1976). *Human characteristics and student learning*. Ney York: McGraw Hill.

- Blonder, R., Mamlok-Naaman, R., & Hofstein, A. (2008). Analyzing inquiry questions of high-school students in a gas chromatography open-ended laboratory experiment. *Chemistry Education: Research and Practice in Europe*, 9, 250–258.
- Bolte, C. (2008). A Conceptual Framework for the Enhancement of Popularity and Relevance of Science Education for Scientific Literacy, based on Stakeholders' Views by Means of a Curricular Delphi Study in Chemistry. *Science Education International*. Vol. 19, No. 3, pp. 331-350.
- Erduran, S. (2001). Philosophy of chemistry: An emerging field with implications for chemistry education. *Science & Education*, 10, 581-593.
- Erduran S., & Duschl R (2004) Interdisciplinary characterizations of models and the nature of chemical knowledge in the classroom. *Studies in Science Education*, 40, 111–144.
- Holbrook, J. (1998). Operationalising Scientific and technological Literacy – a new approach to science teaching. *Science Education International*, 9(2), 15-19.
- Holbrook, J. & Rannikmae, M. (2007). The Nature of Science Education for Enhancing Scientific Literacy. *International Journal of Science Education*, 29(11), 1347-1362.
- Fairbrother, R. W. (2000). Strategies for learning. In M. Monk and J. Osborne (Eds.), *Good practice in science teaching* (pp. 7-24). Philadelphia: Open University.
- Fraser, B. (1982). How strong are attitude and achievement related? *School Science Review*, 63, 557-559.
- Irwin, J. (1997). Theories of burning: A case study using a historical perspective. *School Science Review*, 78, 31-37.
- Justi R., & Gilbert J (2002) Models and modelling in chemical education. In: Gilbert JK, de Jong O, Justi R, Treagust DF, van Driel JH (eds), *Chemical education: towards research-based practice*. Kluwer, Dordrecht, pp 47–68.
- Koballa Jr., T. R., Crawley, F. E., & Shrigley, R. L. (1990). A summary of science education 1988. *Science Education*, 74, 369-381.
- Lindahl, B. (2003). *Changing the subject and teaching to get more students to science and technology?* Paper presented at the GASAT 11 conference, Mauritius.
- Mamlok, R. (1995). *Science: An ever-developing entity*. Rehovot, Israel: Weizmann Institute of Science (in Hebrew).
- Mamlok, R., Ben-Zvi, R., Menis, J., & Penick, J. E. (2000). Can simple metals be transmuted into gold? Teaching science through a historical approach. *Science Education International*, 11(3), 33-37.
- Mamlok-Naaman, R., Ben-Zvi, R. & Hofstein, A., Menis, J., & Erduran, S. (2005). Influencing Students' Attitudes towards Science by exposing them to a Historical Approach. *International Journal of Science and Mathematics Education*, 485-507.
- Matthews, M. R. (1994). *Science teaching: The role of history and philosophy of science*. New York: Routledge.
- Milner, N., Ben-Zvi, R., & Hofstein, A. (1987). Variables that affect students' enrollment in science courses. *Research in Science and Technological Education*, 5, 201-208.
- National Research Council (1996). *National Science Education Standards*. Washington, DC: National Academy Press.
- Nussbaum, J. (1989). Classroom conceptual change: Philosophical perspectives. *International Journal of Science Education*, 11, 530-540.
- O'Neill, D.K. & Polman, J.L. (2004). Why educate “Little Scientists?” Examining the potential of practice-based scientific literacy. *Journal of Research in Science Teaching*, 41, 234–266.
- Organization for Economic Co-operation and Development, (OECD/PISA/SFEG) (2004). The PISA framework for science assessment. Retrieved December 5, 2004, from <http://www.pisa.oecd.org/science>.

- Osborne, J., & Dillon, J. (2008). *Science education in Europe: Critical reflections*. London: The Nuffield Foundation.
- Pintrich, P. A., Marx, R. W., & Boyle, R. A. (1993). Beyond cold conceptual change: The role of motivational beliefs and classroom contextual factors in the process of conceptual change. *Review of Educational Research*, 63, 167-199.
- Simpson, R. D., & Troost, K. M. (1982). Influences on commitment to and learning of science among adolescent students. *Science Education*, 66, 763-81.
- Sjøberg, S. (1996, November). *Scientific literacy and school science – arguments and second thoughts*. Paper presented at the Seminar on Science, Technology and Citizenship. Oslo, Norway.
- Stigler, J.W. & Hiebert, J. (1999). *The teaching gap: Best ideas from the world's teachers for improving education in the classroom*. New York: Free Press.
- Streller, S. & Bolte, C. (2007). "Chemistry (in) the Extra-Class": An Out-of-School-Course to Enhance Students' Interest in Chemistry. Proceedings of the European Science Educational Research Association (ESERA), Malmö.
- Thagard, P. (1992). *Conceptual revolutions*. Princeton, NJ: Princeton University Press.
- Yager, R.E. (2007). The Six "C" Pyramid for Realising Success with STS Instruction. *Science Education International*, 18(2), 85-91.