Teaching Biotechnology Through Case Studies—Can We Improve Higher Order Thinking Skills of Nonscience Majors?

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ABSTRACT: Teaching nonscience majors topics in biotechnology through case studies is the focus of this research. Our *Biotechnology, Environment, and Related Issues* module, developed within the *Science for All* framework, is aimed at elevating the level of students' scientific and technological literacy and their higher order thinking skills. The research goal was to investigate nonscience major students' ability to use various thinking skills in analyzing environmental and moral conflicts presented through case studies in the Biotechnology Module. The research population consisted of about 200 nonscience majors in eight classes of grades 10–12 from heterogeneous communities. We found a significant improvement in students' knowledge and understanding and higher order thinking skills at all academic levels. The scores that low academic level students achieved in the knowledge and understanding category were higher than their high academic level peers' scores. In the higher order thinking skills—question posing, argumentation, and system thinking—a significant difference in favor of the high academic level students was found. The gap that had existed between low and high academic level students narrowed. Most students reported that the biotechnological topics that they had studied were interesting and relevant. Based on these results, we advocate a curriculum that exposes students to scientific controversies through case studies with environmental and moral implications. Our research has shown that this approach is likely to contribute to developing scientific and technological literacy along with higher order thinking skills of nonscience majors. *Sci Ed* **87:**767–793, 2003; Published online in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/sce.10081

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INTRODUCTION

A significant decline in the number of high school students electing science courses in Israel, along with insufficient scientific literacy among nonscience majors and relatively low scores in international assessments, motivated the Israeli Ministry of Education to call for a reform in science teaching. A major recommendation of the Harari National Committee (Harari, 1994) was to integrate Science, Technology, Environment, and Society topics within the framework of teaching *Science for All*.

In order to teach science in a more relevant, meaningful, and appealing way, we adopted the Science–Technology–Society (STS) framework for the development of our learning materials and teaching strategies. Providing science curricula with social context by inclusion of STS issues has been viewed both as a means for promoting awareness of the social, political, and economic dimensions of science and as opening science to females and disadvantaged student populations (Hughes, 2000). Referring to a certain part of the student population as "burnouts," Eckert (1989) noted that these are students who were actively neglected by the society and the school system. In Israel, however, some of the nonscience majors have difficulties mastering science, while others intentionally elect to major in liberal arts. Softening Eckert's expression, both of these nonscience majors can be considered as "science burnouts" in the sense that they have had several years of frustration in junior high school as they were stigmatized as not being able to cope with science. The science curricula in Israel prior to the Harari reform in the mid-nineties was designed to teach science as if all students were going to major in science, failing to recognize the needs of the nonscience student population.

In this study, the *Biotechnology, Environment, and Related Issues* module was developed as part of this national reform of curriculum development for students who do not choose to major in one of the scientific disciplines in the high school. The module, which was developed by a team of high school teachers advised by science educators, presents aspects and dilemmas of research and development in biotechnology and the impact of the technology on society and the environment. The teaching methods were designed to foster knowledge and understanding of key issues, promote socioscientific discourse in class, and encourage higher order thinking skills. These skills included identifying environmental and moral dilemmas, posing questions, providing arguments, and applying system thinking. While learning the module, the students were engaged in studying controversial biotechnology case studies. The research presented in this paper has brought up a variety of issues related to teaching higher order thinking skills to heterogeneous student population. These include teaching for reasoning and encouraging the use of arguments (Carlsen, 1993; Hogan, Nastasi, & Pressley, 2000; Russell, 1983; Yerrick, 2000), dealing with controversies revolving around biotechnology applications (Geddis, 1991), fostering higher order thinking skills (Resnick, 1987; Zohar, 1996), and narrowing the gap between high and low academic level students (Dori & Herscovitz, 1999; Resnik, 1987; Yerrick, 2000; Zohar & Dori, 2003).

Teaching the Biotechnology Module, using controversial case studies resulted in improving students' knowledge, understanding, and higher order thinking skills at all academic levels. The students and the teachers expressed interest in learning the controversial issues and both students and teachers appreciated the learning environment that allowed the development of classroom discourse. The achievement gap that had existed between low and high academic level students was narrowed. This paper presents the module and the learning environment while focusing on students' outcomes at different levels of assignments. Implications on teaching thinking skills to nonscience majors in general, and low achieving students in particular are discussed.

THEORETICAL BACKGROUND

The *Science for All* reform has emerged following a consensus about the need to improve the scientific literacy of students and the vast population (American Association for the Advancement of Science [AAAS], 1989; Bingle & Gaskell, 1994; Bybee, 1993; National Research Council [NRC], 1996; Solomom & Thomas, 1999). There is a substantial agreement that important aspects of scientific literacy are influenced by everyday life (AAAS, 1993; Krajcik et al., 1998; Solomon, 1992, 1994). The *Science for All* reform in Israel implies that students who traditionally did not elect any scientific subject matter as their major participate in newly designed courses. These courses address the characteristics, interests, and needs of these students, who often differ from the typical science major student.

STS is based on ideas of incorporating social, cultural, environmental, political, and ethical aspects into the curriculum (Aikenhead & Ryan, 1992; Bybee, 1987; Kumar, 2000; Pedretti, 1996, 2002; Yager & Hofstein, 1986; Yager & Penick, 1988; Yager & Tamir, 1993). STS curriculum developers worldwide incorporate into the learning materials issues such as genetic engineering, nuclear power, climate changes, and sustainable development. The curriculum is aimed at promoting students' understanding of socioscientific issues, and making informed, responsible decisions (Kumar & Chubin, 2000; Pedretti, 1996; Solomon, 1993; Solomom & Aikenhead, 1994). The students are expected to apply moral reasoning and critical thinking while acting towards the improvement of their environment (Pedretti, 2002). These students—our future citizens—need to be able to make decisions in a highly complex world, where it is often difficult to distinguish between mass media directed contents and respected claims, which are supported and validated (Bingle & Gaskell, 1994).

Kelly (1990) suggested that ethics should be taught as part of science education within a historical framework. Ethics requires the combination of knowledge, morals, and emotions, and entails empathy. Referring to ethics and values in science education, Kormondy (1990) argued that the appropriate approach of teaching ethical issues should be neither didactic nor authoritative. Rather, it should be done in a Socratic, exploratory mode. Questions students pose may be more important than getting answers (Penick, Crow, & Bonnestetter, 1996). Ethics, no less than science, aims at objectivity, depends on justification, and is open to critique (Allchin, 1998).

STS can be taught separately and complementary to science, as a short addendum at the end of selected science chapters, or it can become a major framework for designing the science curriculum (Aikenhead, 1994; Pedretti & Hodson, 1995; Solomon & Thomas, 1999). In such cases, socioscientific issues can serve as the organizers for science education and not as additional illustrative ideas. There are many advantages in using such issues as the core topics of the curriculum. They allow further inquiry, encourage the search for new information, represent excellent examples for interdisciplinary topics, and foster the emergence of continuous discourse (Hughes, 2000; Ramsey, 1993).

One can teach in the STS approach through noncontroversial issues, such as energy conservation, pollution, or preservation of rare species. An alternative design encourages the use of meaningful controversies (Bingle & Gaskell, 1994). Incorporating controversial issues and science and technology conflicts is a recommended method for enhancing students' interest, motivation, and improving their system thinking (Chen & Stroup, 1993). In order to use controversies as organizers in a curriculum, one has to use arguments frequently and adequately. Driver, Newton, and Osborne (2000) developed the case for argumentation as the core activity of scientific practice. They claimed that in order to develop deep understanding and evaluative skills, students must acquire the ability to construct arguments and engage in dialogic thinking. Arguments can be based on scientific claims or on social foundations. Ignoring the social perspectives of science means teaching in a value-free, abstract, and objective approach, which does not reflect our complex modern world (Bybee, 1993; Solomon, 1994). Although objectivity and value-free teaching offer great comfort to science teachers and fit the public conceptions about scientists and science, Allchin (1998) argued that teachers and educators must challenge this comfort. Science teachers usually lack background in sociology, politics, ethics, economics, and law that a socioscientific debate requires. Nor do some of them have the experience necessary to handle controversies, where several viewpoints require consideration (Fensham, 1988). Science teachers avoid addressing values because they see them as belonging to a domain outside of science, or worse, teachers "see themselves betray the very core of science" (Allchin, 1999, p. 9). Discussing values while experiencing learning science in a constructivist setting, students are expected to understand the reasoning that supports the epistemic values and to be capable of questioning and discussing them.

Applying the STS approach, teachers and students can acquire both intellectual and ethical skills, which are instrumental in investigating opposite attitudes, examining potential benefits and costs, and perceiving the political and social forces that drive scientific and technological development (Pedretti, 1999). Benchmarks for Science Literacy (AAAS, 1993) encouraged science educators to address and examine the nature of science and technology in the context of the human society, within which science and technology operate. Achieving these goals requires STS to provide the necessary foundations for students to take action. Although there is a clear need for suitable learning materials and teaching strategies, empirical evidence supporting STS curricular organization, instructional strategies, as well as contents is not sufficient (Cheek, 1992; Posch, 1993; Wiesenmayer & Rubba, 1999).

Thinking Skills and Low Achievers

A major goal of science education is to improve students' higher order thinking skills (Resnick, 1987) and encourage scientific literacy in a social perspective (Driver & Leach, 1993; Pedretti & Hodson, 1995). Vast research literature describes students' scientific thinking. Fostering students' thinking is one of the most ancient goals of education, dating back to the days of Plato in ancient Greece (Resnick, 1987). During many generations, this goal was intended only for a small, restricted group of elite students, while the vast majority of students did not have the privilege of enjoying an educational tradition that fostered their thinking (Resnick, 1987; Yerrick, 2000).

The research literature following Piaget failed to support the infusion of higher order thinking skills into elementary science classes because of the lack of capability of students at this age to perform well on highly demanding tasks (Metz, 1995). Nevertheless, educators argue that thinking should not be viewed as an optional activity that learners may or may not attain at the final stages of their learning (Resnick & Resnick, 1992). Science teachers are aware of their students' reasoning incapability and occasionally address higher order thinking in class. However, they rarely recognize these skills as a distinct, explicit educational goal that should be addressed systematically (Zohar & Dori, 2003). Skills and capabilities, such as posing questions (Cuccio-Schirripa & Steiner, 2000; Dori & Herscovitz, 1999; Scardamelia & Bereiter, 1992; Shepardson & Pizzini, 1991), reasoning (Hogan et al., 2000; Carlsen, 1993; Driver, Newton, & Osborne, 2000; Russell, 1983), problem solving (Pizzini, Shepardson, & Abell, 1989), designing an experiment (Dori, 2003), developing justification skills that allow testing validity and reliability of scientific claims and evidence (Duschl, 1990), and systemic and critical thinking (Chen & Stroup, 1993; Zeidler, Lederman, & Taylor, 1992) are all considered as higher order thinking skills (Ennis, 1962; Resnick, 1987). These skills are not commonly taught at lower track classrooms (Yerrick, 2000).

Learning inherently involves components of inference, judgment, and active mental construction. Thus, the traditional view that the basics can be taught as routine skills, with thinking and reasoning to follow later, as an optional activity that may or may not take place, can no longer guide the educational practice. Instead, *thinking is applied to all learning and to all learners* (Bransford, Brown, & Cocking, 2000; Bruer, 1993; Perkins, 1992; Perkins & Unger, 1999; Resnick & Klopfer, 1989; Resnick & Resnick, 1992). This view, namely that teaching for higher order thinking is important for the learning of all students in all academic tracks, is also emphasized by other researchers (Levine, 1993; Newman, 1990; Peterson, 1988; Pogrow, 1988, 1996; White & Frederiksen, 1998). McNeil (1986) claimed that low achieving students were engaged in minimum efforts in science courses, just to get the credit. Their teachers "collaborated" by teaching defensively, to enable these students to pass these courses without really gaining meaningful scientific knowledge.

Graham, Taylor, and Hudley (1998), who explored ethnic achievement values among ethnic minority early adolescents, distinguish between self beliefs about ability ("Can I do it?") and desire ("Do I want it?"). These are concerned with the perceived importance, attractiveness of achievement activities, or usefulness for the student's future career. In the context of our research we observed a similar perception pattern amongst minority (Arab) and under-achieving students.

Resnick (1987) referred to the idea of *Thinking for All* in an eloquent way by saying that fostering students' thinking is one of the most ancient goals of education. As noted, this goal was intended only for a small group of students, while the vast majority did not enjoy an educational tradition that fostered their thinking. Therefore, says Resnick, there is nothing new in including the teaching of higher order thinking and problem solving in the curriculum of *some* students. Including this goal in the curriculum of *all* students is, however, an educational innovation. A similar idea is also expressed in the STS approach, discussed earlier.

The term *higher order thinking skills* is used in this study to characterize cognitive activities that are beyond the level of understanding according to Bloom's traditional taxonomy (Bloom, 1956). Thus, recall knowledge and understanding of information are classified as lower order thinking skills. Analyzing information and data presented in case studies, posing questions, providing scientifically grounded arguments, expressing opinions, making decisions, and system thinking would be classified here as higher order thinking skills.

In the light of all the above, the design principles for the Biotechnology Module were as follows:

- Framework—using STS approach throughout the module rather than adding STS issues at the end of the learning materials.
- Thinking skills—advocating teaching of higher order thinking to all students. The learning activities were designed around case studies, which raised various questions and encouraged the students to express a wide range of thinking skills.
- Learning experiences—incorporating real-world controversies as well as imaginary stories in order to enhance students' interest and involvement.
- Discourse—encouraging small group and whole class discussions. Creating opportunities for students to present and critique their ideas.

RESEARCH GOAL

The research goal was to investigate nonscience major students' ability to use various thinking skills in analyzing environmental and moral conflicts presented through case studies in the Biotechnology Module.

THE BIOTECHNOLOGY MODULE

The Biotechnology, Environment, and Related Issues module (in Hebrew) was developed according to the design principles presented earlier. It emphasizes ethical and moral dilemmas while providing the necessary scientific knowledge about biotechnology and genetic engineering in a case study format. The module includes the following four chapters, dealing with core issues in biotechnology research.

1. *Agriculture: Increasing quality and quantity*: This chapter introduces the concept of genetic engineering by cases of interfering with reproduction rate, protein production in plant tissues, and possible relationships between genetically transformed organisms and the natural environment.
2. *From wine to insulin: Producing essential materials for humans*: In this chapter students learn about making wine and bread as examples for traditional biotechnology. Insulin production is a case of modern production of essential medications. Here, we introduce the concepts of protein, enzyme, bacteria, and DNA.
3. *Genetic identity*: We discuss the human genome project, DNA fingerprinting and other possible applications. Students learn the concepts of restriction enzymes, chromatography, and electrophoresis and experience them in class. During this phase the students visit a winery or a dairy products factory and a factory that produces plant tissues by cultures and genetic engineering.
4. *Changing genetic characteristics*: In this last chapter, students grapple with issues of gene therapy, changing human genetic traits, and cloning organisms, in case studies such as the sheep Dolly.

The scientific core of the module deals with processes used by ancient industries, such as wineries and baking, as well as advanced industries that apply scientific knowledge about DNA, cells, and organs. While debating problems and disagreements regarding research and application, students come to realize that biotechnology potentially contributes to the improvement of agriculture and medicine and may benefit human kind.

The technological aspect relates to the use of microorganisms and enzymes, produced from living cells in industrial biochemical processes. Social aspects concern environmental and economical considerations, global-political conflicts regarding resources, and the gaps between Western and Third World countries. Last but not least, the moral aspect attracts students' attention, and pragmatics vs. moral considerations are discussed throughout the module. The concluding activity culminates in a public debate about the use of genetic engineering for manipulating human traits.

The major issues in the Biotechnology Module are presented as case studies. Originating from business and medical schools (Herried, 1997), the case study method has become a means for effective learning that draws the attention of the student audience by portraying real-life scenarios. Studies related to teaching students at various ages, using case studies (Dori, 1994, 2003; Dori & Herscovitz, 1999; Tal, Dori, & Lazarowitz, 2000) have indicated that the case study method is effective for raising students' conceptual understanding, question posing and critical thinking abilities, as well as their motivation. Case studies that involve ethics and values engage students in higher order thinking processes more than just focusing on a specific subject matter. Indeed, Allchin (1999) and Driver, Newton, and Osborne (2000) argued that students should be able to discuss moral dilemmas rather than making them recite standard answers. We have adopted the following definition for an educational value dilemma (Stahl, 1979, p. 183).

> Planned content-centered learning activity that is designed to assist students comprehend subject matter content, develop decision making skills, and engage in value and/or moral reasoning processes. Well-constructed value dilemmas often require students to state, clarify, and use their values and their moral beliefs

Most of the case studies were adapted from scientific literature (Gavaghan, 1999; Heller & Eisenberg, 1998; Meade, 1997; Pennisi, 1997). An illustrative case study with built-in dilemma and the learning assignment is presented in Figure 1.

Enrichment materials, glossary, and recommended references follow each section of the module. These include scientific texts, videotapes, laboratory experiments, and field trips. The activities exposed students to the idea that there are questions, which may have several possible answers. For some questions no single answer is necessarily the only correct one, while for others no answer has yet been found.

An illustrative case study from the Biotechnology Module

The advances of biotechnology have changed the attitude towards plants from mere food providers to factories of vaccines. The idea is to provide people with vaccines as part of their daily diet. These vaccines would be much cheaper than the conventional ones, because it is much easier to grow large quantities of plants compared to lab animals or tissue cultures, which are the current origin for vaccines. The most dramatic impact would be on the population of developing countries who would gain accessibility to these eaten vaccines. These countries suffer from deficiency of means for refrigerating, producing, and transporting the vaccines. Researchers transplanted a gene of one of the important proteins of Hepatitis B virus into Tobacco plants. The modified plants started to produce the typical protein of the virus. Mice that were injected with this protein showed to be immune to Hepatitis B without getting ill.

In another experiment, a gene from E. coli bacteria was inserted into the genome of a potato. This bacterial gene is responsible for the production of a bacterial protein, which causes diarrhea in humans. The gene was modified so that while its shape did not change, the protein it produced ceased to be harmful. The result was that the mice that ate the transgenic potatoes developed antibodies for the toxic protein, though they did not get sick.

The possibility of producing vaccines in a similar way is exciting, but accomplishing this goal is still remote. Another factor, which the researchers have to take into account, is the flavor. The food that contains the vaccine should be tasty or at least edible...

The assignment that follows this case study is presented below. The brackets contain the thinking skills the student is expected to demonstrate.

An Evolving Industry – An illustrative assignment that follows the case study

1. *What is the scientific-technological innovation presented in this story?* [knowledge and understanding]
2. *What could be a possible advantage for developing countries?* [system thinking]
3. *Environmental organizations sometimes oppose similar projects, of modification of natural traits of plants and animals. What, in your opinion, is the reason for their opposition?* [argumentation]

Figure 1. An evolving industry.

RESEARCH POPULATION

Israeli students elect their major subject matter at the end of ninth grade. Students who do not elect science may, therefore, graduate high school without participating in science courses. Harari's (1994) recommendations attempted to change this situation by introducing the *Science for All* curriculum to nonscience majors.

Our research population consisted of about 200 nonscience majors in grades 10–12. They came from eight classes in six different high schools with various community and ethnic backgrounds. The students were classified into three academic levels by both their pretest mean scores and their teachers' documentation. The differences among the three academic levels were significant (see Table 1).

The scientific background of the teachers who were involved in the study was diverse. These teachers consisted of two partially overlapping groups. The first group consisted of six teachers, who were involved in the development process of the Biotechnology Module. The first and second authors of this paper provided the academic and curricular support for the module development, while the third author led the developing teachers group and was also one of the experimental teachers.

The second group of teachers, who from now on will be referred to as the experimental teachers, consisted of seven teachers, three of whom also took part in the development of the Biotechnology Module. The experimental teachers had B.Sc. or M.Sc. degrees in biology, environmental studies, food engineering, or chemistry and 6–21 years of teaching experience. They taught the module in their experimental classes after participating in professional development workshops and took part in developing the pre- and posttests, which served as assessment means.

INSTRUMENTS AND DATA COLLECTION

The research instruments included pre- and posttests, teachers' interviews, and students' feedback, as reported in their portfolios.

The tests were designed to examine knowledge and understanding of concepts, application of previous knowledge to new situations, question posing, argumentation skills, and system thinking. They included definitions of concepts, multiple choice items, and case studies with open ended responses. The pre- and posttests were similar in their structure and number of items, but not identical. Three science educators validated the tests and decided on the scoring scheme.

Types and Levels of Assignments

Resnick (1987) stated that although we cannot define higher order thinking skills, we can recognize them when they occur. Complexity, multiple solutions, value judgement,

TABLE 1
Mean Scores, Standard Deviations and *p* Value of the Research Populations by Tukey's Studentized Range Test of the Students' Scores in the Pretest

Academic Level	*N*	$\bar{X}_{Pretest}$	SD	MSE	DF	*p*
Low	78	15.2	12.6			
Intermediate	54	28.7	15.6	2.22	198	<0.05
High	69	42.1	18.0			

uncertainty, and self-regulation are examples of higher order thinking skills. Ennis (1962, 1987) listed various aspects of critical thinking that included judgment of ideas, judgment of validity and conclusions, dialogic thinking, and argumentation.

Based on Costa (1985), Dillon (1990), Shepardson and Pizzini (1991), and using TIMSS (Shorrocks-Taylor & Jenkins, 2000) taxonomy, we applied two levels of assignments in both the module and the tests:

(a) Low level assignments, which require the students to recall knowledge and understand concepts. A typical assignment at this level was a set of multiple choice questions or concept definitions.
(b) High level assignments, which require the students to pose questions, apply previous knowledge or scientific principles to new situations, draw relationships among stakeholder positions, provide arguments and opinions, and evaluate cases. Assignments at this level required open-ended responses.

The low level assignments included two questions that required defining a concept in biotechnology and giving an example, and two multiple-choice questions. The student had to respond to three out of these four assignments. In the high-level part, we presented a case study with four assignments, which included posing questions, implementing previous knowledge to a new situation, making judicious decisions (argumentation), and expressing system thinking. Here too, the students were able to choose three out of four assignments.

Below are two examples for low level assignments.

Definition: Please define or explain what *Microorganisms* are and give an example.

Multiple-choice question: What type of cell would you choose in order to insert a segment of DNA that carries a desired characteristic, so the descendant will carry this characteristic?

(i) The blood cells of one of the parents.
(ii) The blood cells of the descendent.
(iii) The blood cells of both parents.
(iv) The fertilized egg cell.

The students were requested to select the correct item (iv) and explain their choice. The following *Sports champion case study* example illustrates the type of high level, case-based assignment in the posttest. The students were introduced to an imaginary case study of cloning people in order to develop a characteristic of potential excellence in sports by modifying a human embryo genome. Below is an assignment that followed this case study. It required expressing student's opinion regarding the following statements while supporting it with arguments:

- Genetic interference in fetuses that will lead to the development of sports champions' characteristics should be approved.
- Genetic interference in fetuses should be approved under special circumstances.

We refer to this case study also in the sequel within the Findings section. Examples of additional high level assignments and students' responses are presented in Table 2.

Students' responses were collected and classified into (1) the knowledge and understanding category and (2) the higher order thinking skills category. The latter category included posing questions, presenting arguments, and system thinking. Each category was analyzed

TABLE 2
Examples of Students' Responses to High Level Assignments

Assignment	Required Thinking Skill(s)	Adequate Response	Insufficient Response
Why is the use of restriction enzymes for modifying DNA considered a technology? Explain.	Application	"The scientific knowledge is that there are enzymes that cut parts of the DNA from one organism and transplant it to another organism's DNA. This way we can get required traits or substances, such as Insulin for treating diabetes." *The student refers to both scientific knowledge and the benefit to mankind.*	"Using enzymes is a technology in itself. There are doctors who do it manually but the development of science provides the knowledge to cut and assemble DNA." *Misconception of the scientific knowledge part.*
Pose questions that refer to a given case study.	Question posing	"What are the chances for mutations when the Growth Hormone gene is transferred from an animal cell to a bacteria cell?"	"What is a growth hormone?" *The answer to this question requires only knowledge.*
The biotechnology factory case study presents a dilemma of building the factory in the neighborhood. Propose arguments for and against building this factory.	Argumentation	"Should the factory be allowed to continue its operation? Pros: The factory contributes by developing biotechnology in general and medications in particular. Many people are employed and support	"The dilemma is whether bacteria can transfer through sewage. Citizen: I'm afraid of harming my environment or myself. Engineer: We are responsible that such events will never happen."

		their families. The product, Growth Hormone, is needed and can cure many people. Cons: Various bacteria can develop and spread in the region and cause great damage . . . suspicious substances were found in the local sewage system and they can eventually affect our water resources and poison fish." *The answer includes various reasoned opinions—dialogic argument.*	*The student does not point out what is the dilemma. He does not explain how damage to the environment is done and what causes the sewage contamination.*
The sportsmen case study deals with the relationships between science and society. Explain how, in this case, society affects science and vice versa.	System thinking—understanding how science and society affect each other	"Society can affect science by organizing groups of opponents that would prevent any development in the field of genetic engineering in humans for the purpose of getting better sportsmen. This will suppress scientific development. Science can influence society by having people ask for interference in human genetics, which would affect appearance or intelligence only because they are scientifically doable."	"Society affects science in that people who do sports want to have better achievements. Therefore, they would like to have genetic interference. Science develops in various directions and the better ones are expected to be applied to humans. Science expects to find out whether there are natural limitations, therefore we need experiments." *The answer includes inadequate and vague knowledge. The arguments are general declarations.*

both separately (scoring 100%) and as part of a total score. Three science education experts validated the content analysis categories and their scoring and achieved 90% judgmental agreement.

The total score for each student was computed as a weighted average, with a weight of 0.3 assigned to the student's knowledge and understanding, and 0.7 to her or his high order thinking skills. The weights reflect the relative importance we attribute to higher order thinking skills with respect to knowledge and understanding skills. The benefit of applying two scoring schemes is that they yield a separate score for each category (low and high thinking), while the total score provides an overall picture of each individual student, each class, and the entire research population.

Refining the analysis of higher order thinking skill scores, we looked separately at the scores of question posing, argumentation, and system thinking. Low and high academic level students were compared for each of these three high level thinking skills.

As the students were engaged in creating portfolios (which are not discussed in this paper), we examined their attitudes towards the module content, teaching approach and the assessment methods.

FINDINGS

Examining the change between the tests for the entire population, we found a significant improvement ($t = 22.8$; $p < 0.0001$) from the pretest ($\bar{X} = 28.0$) to the posttest ($\bar{X} = 70.7$). The effect size was 2.27. In each one of the three academic levels (see Table 3), students significantly improved their total scores in the posttest.

A Tukey's Studentized Test of the higher order thinking skills category established that the extent of improvement (net gain) of high academic level students' performance in these skills was not significantly different than that of the intermediate academic level ones. However, when high and intermediate academic level students together were compared with low academic level students, a significant difference in the net gain was found. Based on this finding, from this point on we compare only two groups of students: high vs. low academic level students.

Analysis of Student Scores by Categories

To better understand the benefits students gained while learning the Biotechnology Module we present the results according to the two categories: knowledge and understanding, and higher order thinking skills.

TABLE 3
Mean Scores, Standard Deviations, and *t*-Test of Repeated Measurements of the Students' Scores in the Pre- and Posttests Sorted by Academic Levels

Academic Level	Test	N	$\bar{X}$	SD	Net Gain	t	p
High	Pre	69	42.1	17.7			
	Post	48	73.0	23.0	29.9	10.52	0.0001
Intermediate	Pre	54	27.6	15.6			
	Post	49	70.3	22.5	41.5	11.81	0.0001
Low	Pre	78	15.2	11.3			
	Post	68	69.3	24.6	54.2	17.7	0.0001

In the knowledge and understanding category, low academic level students achieved higher scores than their peers at the high academic level in the posttest (Figure 2a). In the higher order thinking skills category (Figure 2b), high academic level students achieved higher scores in the posttest than their peers in the low academic level. This may be an indication that teaching biotechnology in an STS approach with discussions about scientific and social issues, contributes towards narrowing the gap in the knowledge and understanding category to a higher extent than in the higher order thinking skills category.

Examining students' net gain, we found a similar pattern for both categories. The net gains in both categories were significantly higher for the low academic students compared with their high academic level peers ($t = -5.24$, $p < 0.0001$).

Analysis of Higher Order Thinking Skill Scores

One important objective of the Biotechnology Module teaching approach was to encourage students to improve their higher order thinking skills. To gain deeper insight, we investigated the three higher order thinking skills separately. As noted, the students were given the option to choose three out of four assignments that require higher order thinking skills. We found that high academic level students preferred assignments that required question posing, while low academic level students chose mainly assignments that required question posing and system thinking. No difference was found between the two groups of students with respect to choosing assignments that required argumentation.

High academic level students scored significantly higher relative to low level students in higher order thinking skills (see Table 4). The average scores for both academic levels decreased from question posing to argumentation and from argumentation to system thinking. This finding indicates the relative complexity level of these three thinking skill types, with question posing being the least complex and system thinking being the most complex.

It is worth noting that the success of the high academic level students can be attributed, among other things, to the fact that they assessed the difficulty of the different assignments better than their low academic level peers. Within the higher order thinking skills category, they chose questions of argumentation type more than system thinking questions, and succeeded more in the former type than in the latter. Low academic level students, on the other hand, chose the system thinking questions more than argumentation ones, but succeeded less in the former type than in the latter one.

Analysis of the net gain scores for question posing and system thinking skills showed no significant difference in the improvement of low vs. high academic level students. Only

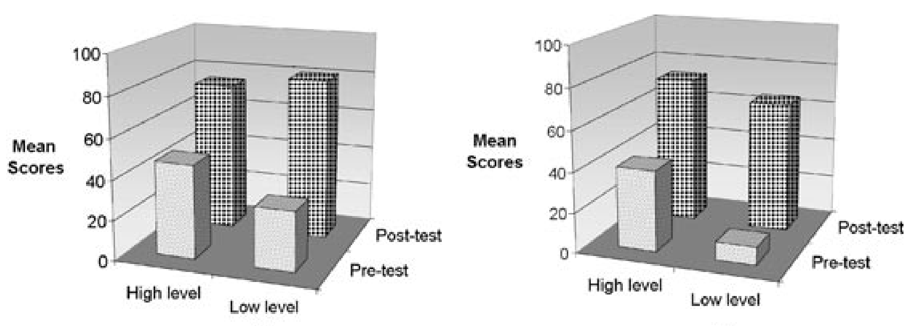

Figure 2. Scores in the pretest and posttest for high and low level students. (a) Knowledge and understanding; (b) higher order thinking skills.

TABLE 4
Mean Scores and *t*-Test of Three Higher Order Thinking Skill Scores in the Posttest for Low and High Academic Level Students

Higher Order Thinking Skills	High Academic Level		Low Academic Level			
	%	$\bar{X}$	%	$\bar{X}$	t	p
Question posing	100	90.4	87	72.9	3.56	0.0007
Argumentation	67	84.9	66	66.3	3.65	0.0004
System thinking	61	77.6	72	54.8	3.76	0.0003

in argumentation the improvement of low academic level students was significantly higher than their high academic level peers ($t = 4.23$, $p < 0.0001$).

Analysis of Student Arguments

An argument can be defined as an individual activity through thinking and writing, or as a social activity taking place within a group (Driver, Newton, & Osborne, 2000). Our students used arguments both as individuals and as a group engaged in class discourse.

Students' individual arguments for the sportsmen case study were collected, classified and initially clustered into two groups: (1) argument's content or domain and (2) argument's moral aspects. Then, each group was analyzed for refined criteria. The criteria for the argument's content are listed and illustrated in Table 5, while their distribution is presented in Figure 3.

Two hundred sixty two arguments were collected from 112 students in four classes. Medical aspects constitute the largest argument category (36%). The arguments also included a considerable amount of social aspects (29%) and moral aspects (11%), demonstrating the impact of the STS approach that the *Biotechnology, Environment, and Related Issues* module induced.

We expected the students to provide a dialogical argumentation by providing reliable claims to support their position and convince their peers. Following Berg (1998) and Kasher (1985, 1998), we refer to moral aspects as human ability to relate to dilemmas that involve value judgement. We determined three moral aspects based on the following three questions.

i. Does the argument contain a value-based consideration?
ii. Does the argument contain an authentic claim?
iii. Does the argument refer to a general moral principle?

We now explain each of these three moral aspects.

i. *Value-based considerations*: An argument that contains a value-based consideration responds to the problem of the right behavior in a conflict situation. The moral solution is based on a normative judgement that recognizes the conflicting interests (Kasher, 1998). A moral judgment might be expressed by doing or avoiding action, and moral decision is an attempt to justify this decision (Weinrib, 1980). We considered an argument to be a value-based one if it contained any value judgment. Applied to our study, this included any attempt to normatively judge genetic intervention or avoiding such intervention. An illustrative argument of this category is *"Genetic intervention in fetuses should be approved in cases of genetic diseases, as this eliminates human suffering and makes people happy."* Sixty-five percent of

TABLE 5
Students' Arguments and Sample Responses to the Sportsmen Case Study

Criterion	Sample Responses
Medical	
• Potential **contribution** to preventing diseases and disabilities or improvement of life quality	• "I approve of genetic interference in special cases like diseases and internal problems such as P.K.U."
• Inflicting possible medical **damage**	• "Genetic changes could cause mutations or unknown genetic diseases. The consequences are not known."
Religious	
• Beliefs that cloning technologies constitute interference with God's creation	• "God defined man's goals in the world. According to these goals, the right tools were constructed. This is interference with heavenly calculations."
Unnatural	
• Claiming that cloning is against nature	• "We shouldn't do what is unnatural."
Human dignity	
• The uniqueness of humans as individuals should be preserved	• "Human are not an industrial product. We should not produce people with intentionally designed characteristics."
Human rights	
• **Parents** rights	• "People have the right to want their children to be champions."
• **Embryo** rights	• "The modification is an interference with the embryo life without its permission"
Societal	
• The effect of the intervention on **sports**	• "This will improve achievements in competitions like the Olympic games."
• **General** adverse effects on society	• "This will create a superior species that will rule the world."
	• "It will be good to have strong soldiers so we can win wars."
Necessity	
• Reference is made only to the case in point	• "It is not something really important."
	• "It is a privilege to be a champion"

the arguments were classified in this category. An argument could be classified into more than one category. Therefore, the total percentage could exceed 100.

ii. *Authentic claims*: An authentic claim is a claim that is true and can be supported by facts about the issue at hand (Berg, 1998). We classified arguments as containing authentic claims if they were based on knowledge from the domain, which the student usually acquired while studying the Biotechnology Module. Futuristic scenarios were judged on the basis of whether or not they were consistent with principles discussed in the Biotechnology Module, or if they simply made sense. Thus, an argument along the line of *"This will ruin the sport because it is obvious who will win, and with no sweat"* is not acceptable. This argument contradicts the biological principle that the genes only enable the potential for certain qualifications, which must be acquired through interaction with the environment. Moreover, the argument is based on the implicit assumption that recombinant genes are guaranteed to always

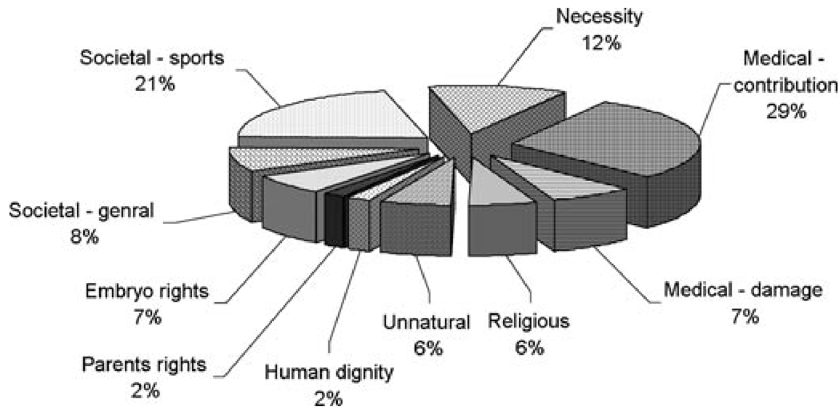

Figure 3. Distribution of argument types within the content category in the sportsmen case study.

yield better characteristics than their natural counterparts. Sixty three percent of the arguments were classified in this category.

iii. *General moral principles*: Any argument that referred to a moral principle (Weinrib, 1980) was classified under general principles category, regardless of its content. Examples include *"Saving life is important"* and *"We should preserve the world in its natural state for the future generations."* Thirty percent of the arguments were classified in this category.

The average number of arguments per student for the sportsmen case study assignment was 2.35. The corresponding number in a similar pretest question was 0.61. This ratio of about 4:1 between the average number of arguments per student in a question that requires argumentation after and before the course was consistent for all three types of value judgement.

Student and Teacher Feedback

The students' feedback related to their attitudes towards the module content, teaching approach and the assessment methods was documented in the students' portfolios. Table 6 cites students' reflections about the module by categories.

About half of the extracted items, which students ($N = 192$) expressed, referred to the interest and importance of the topics they studied in the Biotechnology Module. About one third of the items dealt with the relevance of these topics to the student at both the global and personal levels. About one third of the students indicated that they liked the variety of the teaching methods they had experienced. A few students noted that working on the portfolio contributed to improving student–teacher and student–student relationships.

Some students from an Arab school, who were facing a language challenge, wrote that the portfolio provided them with an opportunity to face the challenge of expressing themselves in Hebrew in a less stressful situation than in a test.

> The advantage of the portfolio was that I could correct mistakes I had, especially in Hebrew, something I couldn't do in the test. This was a new experience for me and helped me improve my work as well as increase my understanding of the subject matter.

The teachers provided feedback on several issues related to teaching the Biotechnology Module: students' interest, content, impact on students of various academic levels, teaching,

TABLE 6
Students' Reflections About the Module (Cited from Their Portfolios)

Category	Examples
Interest	• It is a pleasure to study and find out new and interesting things, of which I was not aware. • The most interesting thing for me was the process in which the genetic substance is transferred from one creature to another. • The cloning of Dolly, the sheep was the most interesting thing. • earning about values and ethics was more interesting than the scientific part. • What interested me the most was the process in which the genetic substance is transferred from one creature to another.
Content	• I'd add more lessons about the genetic engineering controversy. • I'd decrease the pure biology sections and add more relationships with our social life. • I did not like learning about plants. I liked the parts about humans more. • I liked learning about "Ice minus" bacteria, because I learned how genetic engineering might save billions. I never thought that recombinant bacteria could help future generations. • I liked incorporating the study of genetics with real world consequences.
Social relevance	• The subject of food development speaks strongly to me because it is important to the future of the world. • Many social issues are discussed; these issues touch me even personally. • I like it when we address social issues of science. • The sustainable development idea is important because biotechnology offers possible solutions for future generations. • All these great solutions might save human lives all over the world. • I was relieved to know about various solutions for possible biological warfare. On the other hand I learned how easy it is to produce new bacteria.
Personal relevance	• Biotechnology is the future occupation. • I liked the way one can add a characteristic to a plant and then it yields more fruit. *This item was classified as personal because the student's parents have a farm.* • We deal with everyday life. It addresses so many areas of our lives. • This is my future career. I know it now. • The "Kosher" thing was the most relevant for me. I'd like to know if the recombinant foods are Kosher. • I am afraid of vaccines, needles and stuff. I am looking forward to be able to eat tasty vaccines instead of getting injections. • I have a twin sister, so what was important for me is learning about genetic vs. other influences.
Teaching methods	• I liked the role playing and the "public trial" the most • I liked the questions asking method. • I liked working in small groups although we had to read lots of articles. • Visiting the factory was the peak for me. I learned not just about the contribution of microorganisms, but how important is industry in general. • The inquiry project was the most interesting thing. • I liked the questions that do not have one correct answer. It makes you think and use your previous knowledge. • I thought everything a subject needs, was there: experiments, movies, web-browsing for articles, and what was the most interesting thing is the discussions we had in class. • I'd like to have more time to learn these important issues. • I'd like to have more experiments.

and assessment methods. Table 7 presents the teachers' reflections about the teaching process, cited from their interviews.

Regarding content, teachers noted that their level of interest, as well as that of their students, increased as the teaching process progressed. One teacher reported that a parent told her that his daughter was fascinated by a biotechnology topic reported in the news. According to his interpretation this makes science more relevant and less intimidating.

The teachers emphasized the importance of the interdisciplinary nature of the topics and the contribution to students' interest in science. One teacher noted her difficulty in teaching an interdisciplinary topic, which was not within her main area of specialization. This teacher indicated that thanks to the openness during teachers' group meetings and the development of a discourse within this community, she could ask questions and get help from peers and advisors.

Regarding teaching and assessment methods, the teachers listed the experiments, field trips to biotechnology factories and the role-playing in the "public trial," conducted at the end of the course, as a major contribution to meaningful learning. They also appreciated the value of the variety of the assessment methods.

SUMMARY, DISCUSSION, AND FURTHER RESEARCH

The project described in this paper was developed within the *Science for All* framework, and was aimed at elevating the level of students' scientific and technological literacy along with higher order thinking skills. The goal of our research was to investigate nonscience major students' ability to use various thinking skills in analyzing environmental and moral conflicts presented through case studies in the Biotechnology Module.

Findings regarding students' outcomes at the knowledge and understanding and higher order thinking levels indicated a significant improvement in both categories. These findings are in accord with previous research results (Dori, 2003; Dori & Herscovitz, 1999; Tal, Dori, & Lazarowitz, 2000; Yerrick, 2000; Zohar & Namet, 2002). Students at each academic level made significant progress with respect to their level prior to the course. Analysis of student scores by categories showed a tendency to close the gap between the low and high academic level students. In the knowledge and understanding category low academic level students achieved even higher scores than their peers at the high academic level. Although we found a significant difference in favor of the high academic level students in the higher order thinking skills (e.g., question posing, argumentation, and system thinking), the net gains in both categories were significantly higher for the low academic students compared with the high academic students.

Discussion

The research has brought up a variety of issues related to teaching higher order thinking skills using STS approach for teaching nonscience majors. These include teachers' role in this endeavor, dealing with controversies revolving around biotechnology applications, fostering higher order thinking skills, and narrowing the gap between high and low academic students. Next we discuss these issues in the context of this research.

This research shows that both students and teachers appreciated dealing with socioscientific issues. The students acknowledged that these issues are interesting and relevant. They provided arguments for both personal and social relevance and noted the difference between traditional teaching and the variety of teaching methods they experienced in this module. Many students emphasized the value of group and class discussions in addition to the field trips, the role playing, and the experiments. The teachers confirmed the students' comments,

TABLE 7
Teachers' Reflections about the Teaching Process (Cited from Their Interviews)

Category	Examples
Students' interest	• I taught several STS modules to low academic level students. Of all these modules, the biotechnology interested them the most. As time went by, they brought relevant press articles, especially on genetic engineering on their on accord. • Students were very interested in watching "Jurassic Park" and reading the case study about a family with an ethical problem regarding cloning their child. • Disagreements during discussions increased student interest.
Content	• I taught two classes, one high achievers and one low achievers. Students in both classes were mostly interested in "genetic fingerprints," forensic, cloning, and applications in humans. They showed less interest in application in agriculture. • Vaccination and criminal applications were more intriguing to the students. To increase their level of interest in agriculture, I suggest adding examples such as lengthening shelf life of tomatoes. • Topics regarding human life caught the students' attention. They could and did discuss their opinions even before studying the topic in depth.
Impact on students of various academic levels	• Studying the Biotechnology Module contributed significantly to students at all academic levels. Especially, low achievers were actively involved for the first time in science topics that they have heard of before in the media. • This is suitable to all levels with some adaptation. Teaching low achievers I omitted some details while elaborating on the enrichment material for the high achievers. • Other teachers who taught this class claimed it was a low academic class, unfit for matriculation examinations, with behavioral problems. I didn't experience any of these problems, the class was immersed in the learning materials and the discussions.
Teaching methods	• The variety of teaching methods, which included field trip to a biotechnology plant, movies, role-playing in the "public trial," class discussions, and reading articles, gave the students a feeling that this was a special course and boosted their self-esteem. • I fondly recall the "public trial," for which two students acted as the defendant and the prosecutor, while the rest played judges and jury members. The two students prepared themselves for the trial in an extraordinary fashion, reading a lot of auxiliary material. • Due to the emotionally loaded issues that come with genetic engineering, we held plenty of discussions. Almost every discussion was among the students and barely moderated by myself.
Assessment	• I suggest using the "public trial" as an assessment tool as well, especially in low achieving classes because it promotes volunteering. • The portfolio served as a basis for continuous dialog between myself [the teacher] and the students. • The report on the filed trip was very important, it gave the students a sense of real research. • I asked the students to write limericks with their opinions about genetic engineering—pro and con. We held a poetry contest for credit, the class enjoyed the activity immensely.

also noting that the topics in the Biotechnology Module were important, relevant, and appealing to students at all academic levels. Both the teachers and the students indicated that the variety of teaching methods was a major factor in the success of the module.

According to Crawford, Krajcik, and Marx (1999), the teachers are instrumental in exchanging the roles between them and the students and in creating a community of learners. The similar responses of the students and the teachers may support our assumption that the module and its teaching approach contributed to creating a community of learners with its own unique discourse. Teachers' attitudes toward teaching *Science for All* is an important success factor in implementing this endeavor. In a reform process, when the initiative comes from an external source, teachers usually collaborate in cases where the learning materials provide a solution to a pressing educational problem (Wallace & Luden, 1998). The teachers' collaboration in developing the module was facilitated by the need for adequate learning materials that would motivate nonscience majors to engage in meaningful science learning.

A possible explanation for the success of this study is teachers' involvement in the developing of both the curriculum and the assessment tools. This has proven to be an effective strategy for elevating teachers' awareness of the pedagogical potential of the STS approach in general and of related assessment modes in particular (Dori & Tal, 2000; Tal, Dori, & Lazarowitz, 2000). This study, as well as that of Dori & Herscovitz (1999), shows that with the application of appropriate curriculum and instruction, students at all academic levels benefit. The curriculum development evolved in a bottom-up fashion. Several experimental teachers noted that an important lesson had been that involvement of teachers in the development and assessment processes had positively affected their ability to implement the approach that fosters higher order thinking skills through STS in their classes (Tal et al., 2001; Zohar & Dori, 2003).

A host of players with competing interests are involved in making decisions regarding controversial issues that affect our lives. Such issues should therefore be incorporated into effective STS education (Cheek, 1992; Hughes, 2000; Kumar & Chubin, 2000; Pedretti, 1999). Cross and Price (1996) noted that even though teachers indicated they taught controversial issues, this is still done within the traditional science teaching context. Taking this into consideration, we involved the teachers in suggesting and developing alternative teaching methods.

The module *Biotechnology, Environment, and Related Issues* revolves around contemporary biotechnology advances and their implications on both society and the environment. This reflects a long history of relationships between biology and ethics. Ethics requires the combination of knowledge, morals and emotions, and entails empathy and should be taught as part of science education (Kelly, 1990). In view of this, a major issue in the Biotechnology Module concerns moral questions and dilemmas raised by biotechnological innovations. Following this line of thought, we required students to pose questions and analyze case studies using argumentation and system thinking skills. Our approach emphasizes the active role of the students who work in small groups, formulate questions, search for and evaluate evidence, and express their own opinions while making tough decisions in controversial issues. Indeed, the students in this study asked many more questions in the posttest compared with the pretest. Moreover, in the posttest case study, students provided arguments in several aspects, including medical, social, and moral.

These findings are in accord with those of Driver, Newton, and Osborne (2000), who claim that social relations within a group that constructs arguments are important, as they contribute to developing one or more lines of reasoning. Learning and understanding of science in such situations is the outcome of both cognitive and social factors. We believe that the small group and the class discussions, contributed to the development of higher order thinking skills of lower academic level students, as they were encouraged to be engaged in dialogs with peers, express their opinions, and support their viewpoints with scientific evidence. The students' responses to questions that do not have a single answer, and to question about values and ethics, support this. We suggest that these students, who initially avoided participating in class, felt comfortable about expressing their opinions and sharing their thoughts with their classmates.

Graham, Taylor, and Hudley (1998) argued that minority adolescents must cope with dual stressors of negative stereotypes about their group and academic challenge. These stressors undermine the endorsement of achievement values. While this research did not focus on minorities, our students were similarly singled out as low achievers in science. Hence, they, too, had to cope with a negative stereotype. The class atmosphere, which the STS approach induced, helped them overcome this stressor and take part in class discourse.

The importance of argumentation in science education is rooted in the claim that "to know" science encompasses not only what scientific phenomena are, but also how they interrelate, why they are important, and how they affect systems (Driver, Newton, & Osborne, 2000). STS-oriented educators perceive science as part of a broader human activity that involves reasons, values, needs, and critiques of decisions. Our study has demonstrated that adopting the STS approach by encouraging students to express opinions on controversial issues and maintaining class discourse promotes students' scientific literacy and interest. Several researchers who have studied the STS approach (Kumar, 2000; Pedretti, 1999; Solomon, 1994) questioned whether any teaching approach enables learners to express their own opinion. They agree that setting up situations in which students would feel free to discuss controversial issues and be provided with access to pertinent knowledge would be a key feature. The Biotechnology Module aimed to provide our students with these conditions and to enable them to express their opinion on moral and environmental dilemmas. The combination of the Module and the approach of teaching it turned out to be a suitable means for encouraging the students to actively participate in free and open discussions about scientific and social issues.

When teachers participate in programs that are targeted for a heterogeneous student population (in terms of students' social-economic background and academic abilities), they often tend to engage low achieving students in activities that require less thinking than high achieving students (Raudenbush, Rowan, & Cheong, 1993). This tendency is likely to be motivated by good intentions. Teachers view higher order thinking tasks as difficult and therefore avoid assigning these tasks to students, whom they believe, will find them difficult and frustrating. This teachers' view creates a negative feedback cycle: precisely those students whose thinking skills need the most care, get less attention from teachers in this respect. Contrary to many teachers' beliefs, our findings show that fostering higher order thinking skills in science classrooms is appropriate for students at all levels of achievements. These findings are in accord with the STS framework in science education.

By the end of the project, students with high academic achievements scored higher than their peers with low academic achievements on high-level assignments. This pattern is consistent with other studies (Dori & Herscovitz, 1999; Zohar & Namet, 2002; Zohar & Dori, 2003). Moreover, this study has shown that high level students demonstrated better choices by electing suitable tasks compared to their low level peers. These facts do not undermine the importance of our findings, since we are by no means suggesting that our treatment can completely close the gap between low and high achievers. By emphasizing the development of students' higher order thinking skills, improvement in the scientific and technological literacy of students at all academic levels can be achieved. The relativity of this improvement is with respect to each student's initial starting point. In our case, the gap between low and high achievers was narrowed. Students, who were initially classified as low achievers, scored higher than students who were initially classified as high achievers in the knowledge and understanding category. Informal classroom observations and conversations with teachers indicated that the teachers who taught this module tended to emphasize higher order activities with students whom they considered academically "stronger," while emphasizing more drill and information recall activities with students whom they considered "weaker."

These observations, which agree with those of Raudenbush, Rowan, and Cheong (1993), warrant two remarks. First, students from all academic levels supposedly went through the same program. However, teachers engaged students with high academic level in higher order thinking to a greater extent than with low academic level ones. Thus, if teachers would learn to require identical, or very similar higher order thinking tasks from students of all academic levels, the traditional "low achievers" could make an even larger progress in their thinking abilities than this study has shown.

Second, this finding suggests that the issues discussed so far might have an additional aspect. The focus on higher order thinking when teaching students with high academic achievements might cause science teachers to neglect the teaching of scientific concepts. Ideally, teachers and students alike should target both of these learning objectives, without neglecting either one of them.

Educators believe that higher order thinking skills play an important role in science education (Resnick & Resnick, 1992; Zeidler, Lederman, & Taylor, 1992; Zohar, 1996). Nonetheless, many teachers maintain that only high achieving students can develop these skills (Raudenbush, Rowen, & Cheong, 1993). Moreover, the common view is that once low academic level students graduate from high school, they are the ones who are least likely to further develop higher order thinking skills in a scientific and technological context. In view of these commonly held opinions on low achiever abilities, our findings are particularly encouraging, since developing higher order thinking skills amongst the low academic level student population is of utmost importance.

Feedback gathered from teachers and students showed that teaching case studies emphasizing dilemmas in biotechnology was of interest to students and teachers alike. Different levels of relevance of issues and variety of teaching and assessment methods motivated students to develop interest in scientific issues in general and in biotechnological topics in particular.

Research Limitations

One limitation of the research is that the project under investigation was adapted to the requirements of the Israeli curriculum reform. Similar studies should be conducted to generalize the research outcomes to other cultural backgrounds. The study was conducted early on during the implementation of the *Science for All* curriculum. Therefore, there were no students who studied biotechnology in the traditional way, who could serve as a control group to be compared with the case study method.

Another limitation was that not every student responded to all question types in the tests because students had to choose three out of four high level assignments in both the pretest and the posttest. This enabled examining student choice patterns and showed that high level students demonstrated better choices by electing suitable tasks compared to their low level peers. However, this choice provided students with the option to avoid responding to certain types of questions. A new study of this nature can be designed with more questions of each type in each test, such that the likelihood of choosing at least one question of each type would increase. Practically, though, teachers may justifiably object this, claiming that students would loose focus responding to a test that is too long.

Finally, one cannot measure what's on a student's mind. At best, one can only assess students' learning outcomes as a proxy of this thinking. If the students realized that they were expected to express their thoughtful work, this is a step toward thinking at higher levels. A future study may include some kind of a "think aloud" method, which would provide more direct evidence.

Further Research and Recommendations

Further research might investigate the cumulative, long-term effect of teaching a series of *Science for All* modules that feature case studies encouraging the development of students' higher order thinking skills. It might also be interesting to study whether and to what extent these acquired skills are transferable to other subject matters.

Teacher preparation and professional development are another avenue of research. How would a workshop on ethics affect teachers' level of proficiency in dealing with controversial issues and how would this, in turn, affect their students' argumentation? Also, exposing teachers to the findings of our study may contribute to changing teachers' beliefs and habits regarding the issue of teaching higher order thinking skills to low academic students.

In conclusion, modern society citizens should be encouraged to critically examine information that requires knowledge of science and technology. If they can question its quality, express their own arguments based on scientific knowledge, and handle dilemmas through the application of system approach, our efforts to improve students' higher order thinking skills are rewarded. Our study supports the transition from designing curricula to science majors and high achievers only, to designing learning materials to a wider and more heterogeneous student population. Based on our findings, we conclude that a *Science for All* curriculum should expose nonscience major students to science as an interdisciplinary topic, with social and moral implications. Learning materials developed with these ideas in mind would contribute to foster scientific and technological literacy, as well as to higher order thinking skills of all students.

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