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DOI
10.1080/09500690902943665

Publication date
2010

Document Version
Final published version

Published in
International Journal of Science Education

International Journal of Science Education
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/tsed20

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Available online: 17 Jun 2009

To cite this article: Tanja Klop, Sabine E. Severiens, Marie-Christine P. J. Knippels, Marc H. W. van Mil & Geert T. M. Ten Dam (2010): Effects of a Science Education Module on Attitudes towards Modern Biotechnology of Secondary School Students, International Journal of Science Education, 32:9, 1127-1150

To link to this article: http://dx.doi.org/10.1080/09500690902943665

International Journal of Science Education
Vol. 32, No. 9, 1 June 2010, pp. 1127–1150

Routledge
Taylor & Francis Group

RESEARCH REPORT

Effects of a Science Education Module on Attitudes towards Modern Biotechnology of Secondary School Students

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This article evaluated the impact of a four-lesson science module on the attitudes of secondary school students. This science module (on cancer and modern biotechnology) utilises several design principles, related to a social constructivist perspective on learning. The expectation was that the module would help students become more articulate in this particular field. In a quasi-experimental design (experimental-, control groups, and pre- and post-tests), secondary school students' attitudes (N = 365) towards modern biotechnology were measured by a questionnaire. Data were analysed using Chi-square tests. Significant differences were obtained between the control and experimental conditions. Results showed that the science module had a significant effect on attitudes, although predominantly towards a more supportive and not towards a more critical stance. It is discussed that offering a science module of this kind can indeed encourage students to become more aware of modern biotechnology, although promoting a more critical attitude towards modern biotechnology should receive more attention.

Keywords: *Secondary school; Attitudes; Science education; Scientific literacy; Attitudes towards biotechnology; Quasi-experimental design*

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ISSN 0950-0693 (print)/ISSN 1464-5289 (online)/10/091127–24

DOI: 10.1080/09500690902943665

Introduction

Background

As a scientific discipline, modern biotechnology goes hand in hand with cultural, social, and public policy controversies. The development of theories and techniques enables scientists to alter the genetic code of practically all living organisms. Genes and gene combinations, that control a wide variety of traits, are described. Several genetic anomalies causing disorders such as cystic fibrosis, Huntington's disease, and several types of cancer have been identified. Biotechnological applications of all kinds are in the making and already evident in a growing range of genetically modified foods in supermarkets. Discoveries from the field of biology can fundamentally change society and human self-perception in the twenty-first century.

This scientific revolution requires a scientifically literate population, meaning that people should be able to make informed and balanced decisions about scientific issues concerning their careers, their daily lives, and society as a whole (National Academy of Sciences, 1996).

Promoting scientific literacy is widely recognised as a major goal of school science education (Millar, 2006). Although there is considerable agreement about the fact that science education should provide understanding, skills, and values for young people to learn to cope with science in their lives, there is much uncertainty on how to achieve or improve this (DeBoer, 2000; Hodson, 2002; Jenkins, 1990; Kolstø, 2001; Laugksch, 2000). Consequently, there are varying interpretations of how and what kind of abilities should be incorporated into school science curricula in order to help students become scientifically literate. The question is what is important for students to know, value, and be able to do in situations involving science and technology? Current thinking about the desired outcomes of science education emphasises scientific knowledge and an appreciation of science's contribution to society. These outcomes require an understanding of important concepts and explanations of science, and the strength and limitations of science in the world (OECD, 2006). Conceptualisations of scientific literacy range from understanding lay articles in newspapers and popular magazines (Millar & Osborne, 1998), an appreciation of the nature, aims and general limitations of science (Jenkins, 1992), to the abilities of a semi-professional scientist (Hazen & Trefil, 1991; Thomas & Durant, 1987). This paper follows Millar's (2006) starting point in that science education should have the aspiration to include scientific literate competences that students need, to be able to live and participate with reasonable comfort, confidence, and responsibility in a society that is deeply influenced and shaped by the applications, ideas and values of science (Millar, 2006). These competencies require students to demonstrate, on one hand, cognitive abilities, and on the other hand, values, motivations as they meet, and respond to socioscientific issues (SSI) (Bybee, 1997; Holbrook & Rannikmae, 2007; Kolstø, 2001; Shamos, 1995; Zeidler, Walker, Ackett, & Simmons, 2002).

Attitudes towards Modern Biotechnology

The purpose of science education should be helping students to be able to participate in discussions about science, to be sceptical and questioning of claims made by others about scientific matters, and to make informed decisions about the environment, their own health and well-being (in accordance with Driver, Newton, & Osborne, 2000; Goodrum, Hackling, & Rennie, 2001; Kolstø, 2001; National Science Council, 1996). According to Osborne (2000), this broad focus will help students to tackle everyday decisions with a science or technology dimension, such as whether to buy a tube of genetically modified tomato paste.

In this study, we examine the effects of science education on the development of stable, informed, or critical attitudes of students towards modern biotechnology, which are needed to cope with this field of research in every day life. Therefore, it is important to construct a measure that will be sufficiently sensitive to capture changes in the structure of its composition (Millar, 2006). The tripartite theory of attitude (Breckler, 1984; Eagly & Chaiken, 1993; Katz & Stotland, 1959; Rosenberg & Hovland, 1960) provides a helpful framework in the construction of this measure of changes. In general, an attitude can be described as "a summary of evaluations, representing favourable or unfavourable feelings towards a specific or psychological object" (Ajzen & Fishbein, 2000; Eagly & Chaiken, 1993; Weinburgh & Engelhard, 1994; Zacharia, 2003). In this case, the object is modern biotechnology.

According to the tripartite theory of attitudes, attitudinal responses can be classified into three key components: an affective, a cognitive, and a behavioural component (Breckler, 1984; Eagly & Chaiken, 1993; Katz & Stotland, 1959; Rosenberg & Hovland, 1960). The cognitive as well as the affective component influence evaluations, which in turn affect behavioural intentions (Ajzen, 2001; Heijs, Midden, & Drabbe, 1993; Tesser & Shaffer, 1990). In the case of attitudes towards modern biotechnology, in the cognitive component, the evaluation of modern biotechnology follows from beliefs, thoughts, and knowledge of the object. The affective component of attitudes reflects how students feel about genomics, for instance anxieties and fears about this contemporary technology. Furthermore, attitude is one of the important determinants of intentions and behaviour, for example consumption or protest (theory of planned behaviour) (Ajzen & Fishbein, 2000; Armitage & Conner, 2001; Zacharia, 2003). Our line of argument is that when students have a solid knowledge base on basic biological and genetic concepts, when they display an affective reaction of concern or comfort towards biotechnology issues (as opposed to an indifferent reaction), and they have comprehensible ideas on how to behave or make decisions when confronted with modern biotechnology, that is, when students have profound attitudes, they can be considered scientific literate ("genomic literate").

Previous Study on Attitudes towards Modern Biotechnology

According to this line of argument, a profound attitude requires (1) a solid knowledge base of basic scientific constructs (cognitive component), (2) a clear stand on one's own feelings and emotions on important (social and ethical) issues (affective component), and (3) the ability to make informed decisions about the environment, ones own health and well-being (behavioural component).

In a previous study, an attitude instrument (questionnaire) was developed and a sample of 574 Dutch secondary school students was asked to answer this questionnaire in order to determine their attitudes (Klop & Severiens, 2007). Based on principal component analyses, a set of several independent underlying factors within the affective, cognitive, and behavioural components were found (see Table 1 for descriptions). In a subsequent cluster analysis, four interpretable attitude-clusters based on that set of factors could be described, representing four different groups of students (attitude-clusters).

The four emerging patterns were labelled *confident supporter* (22% of the students), *concerned sceptic* (18%), *not for me* (17%), and *not sure* (42%) (see Figure 1 for a graphic representation). The "confident supporters" were a positive, pro-biotechnology and well-informed group of students, who seemed to welcome biotechnology in their daily lives. This group can be labelled as "more scientifically literate", for they seemed to be well aware of scientific concepts and processes, and were able to take a clear position regarding environmental, health, and personal issues. The "concerned sceptics" were also a well-informed group of students, and also labelled as more scientifically literate. Not only did they show a solid knowledge base on basic biological and genetic concepts, they demonstrated a sceptical, concerned, and questioning stance towards claims made about modern biotechnology as well. The smallest group, the "not for me" students, was very negative about biotechnology. Their beliefs and affective reactions were very negative, and unfortunately, they displayed poor knowledge and understanding of the subjects. The last cluster, the so-called "not sure" group, formed the largest group. Their views tended to be rather indistinct and more difficult to interpret; they showed neither anti-biotechnology nor pro-biotechnology affections, and their overall understanding of the subjects was rather diffuse.

In other words, more than half of the 16-year-old students hold a relatively unprofound attitude towards modern biotechnology. These students had a limited knowledge base of the key concepts and principles of modern biotechnology (especially the "not for me" group), and unclear or poorly developed views or opinions on important social and ethical issues. They were not sure about their intentions towards possible biotechnological applications, and were not sure what to expect of genomics in general. Even students with somewhat more knowledge on the subject (the "not sure" group) seemed to have little awareness and showed little care about the possible impact modern biotechnology could have on society and thereby their own (future) lives. In other words, they did not use their "scientific knowledge and ways of thinking for personal and social purposes".

The question is how scientific literacy can be promoted in science classes; in what ways can science education encourage students to learn about (bio-) technological issues concerning society, their careers, and their daily lives, so-called SSI (Sadler, 2002; Zeidler & Keefer, 2003; Zeidler et al., 2002), and develop a critical

Table 1. Attitude factors with scale name, description, typical items, reliability, and descriptive values, based on principal component analyses

Attitude components	Attitude factors	Description	Typical item	Cronbach's alpha (number of items)	Mean (SD)
Cognitive component	Biology and genetics	Knowledge of biology and genetics	DNA contains the information for all your hereditary traits.	.63 (n = 9)	7.10 (1.81)
	Biotechnology	Knowledge of biotechnology applications	Normal tomatoes have, in contrast to GM tomatoes, no genes.	.71 (n = 17)	13.80 (1.80)
	Beliefs	Evaluative knowledge of biotechnology/beliefs about biotechnology	I think genomics can solve food problems in the third world.	.70 (n = 5)	3.09 (0.64)
Affective component	Basic emotion	Basic emotional reactions	Genetic modification (GM) is bad.	.78 (n = 13)	3.00 (0.58)
	Unavoidable	Feelings of biotechnology being unavoidable	Biotechnology is absolutely necessary.	.76 (n = 9)	3.12 (0.62)
	Worries	Worries about biotechnology	How many worries do you have about genetic research?	.79 (n = 5)	2.97 (0.79)
Behavioural component	Own intentions	Intentions to consume; own interests	I would eat GM food if it were cheaper than normal food.	.78 (n = 5)	3.09 (0.82)
	Medical intentions	Medical intentions	Would you take a genetic test during your pregnancy?	.74 (n = 4)	3.10 (0.83)
	Critical intentions	Intentions to consume; critical conditions	I would buy GM food if it were grown more in a more environment-friendly way than normal food.	.74 (n = 3)	3.60 (0.90)

opinion? In order to help young people engage in the social practice of scientists, learning contexts must be chosen so that students can make sense of it, and give them a feeling of responsibility to participate critically. However, at the level of educational practice, inspiring examples are relatively sparse. Moreover, empirical research into the effectiveness of such educational practices appears to be lacking (Hodson, 2003). Therefore, we decided to examine the effects of a new and innovative Dutch science module, on genomics and cancer, on students' attitudes towards genomics. By analysing the design of the science module and the effects of the module on the different attitudinal components of the secondary school students, we hope to contribute to a greater understanding of how to support young learners in developing their need to cope with science in their lives. We will first present the structure of the science module and then make the underlying design principles explicit.

Features of a New Science Module

The genomics research centre of excellence (CGC)[1] of the University Medical Centre, Utrecht developed a new science module for the upper levels of secondary education. The socioscientific topic of the science module is genomics and cancer research; titled "Read the language of the tumour" (*Lees de taal van de tumor*). A so-called "travelling DNA-lab" gives students the opportunity to meet with new and sophisticated research techniques. By giving a realistic picture of genomic-research, the module aims at students' acquisition of knowledge on the subject of genomics. Moreover, it is intended to stimulate the opinion forming and critical reflection of students towards genomics and the implications of the applications on society (Waarlo, 2007).

The science module consists of four lessons; an introductory lesson, two practical/hands-on lessons (in succession), and a reflection lesson. During the introductory and reflection lesson instruction and guidance was given by the teacher him/herself. The practical lessons, a "DNA-lab setting" at school, was supervised by two trained students of the university. Teachers that signed up for the science module received a detailed teacher manual and workbooks for their students.

The introduction lesson included a brainstorm session and opportunity to raise questions on the topic of cancer and cancer research. The lesson was designed to connect with students' prior knowledge of the subject matter, since students were already presumed to have at least some background knowledge and ideas about social or ethical matters relating to cancer and/or biotechnological research. After activating prior knowledge and clarifying ideas or difficulties, students were invited to discuss their questions about and experiences with cancer and cancer research in small groups first and then in the whole class.

During the second and third lessons, students had to perform an assignment in a genomics lab setting. They worked in small groups (two or three students), under the supervision of two university students. In this genomics-laboratory setting, using a hands-on approach, the students were invited to use actual genomic techniques.

This gave them an opportunity to visualise abstract biological concepts: observing (and in some cases touching) preserved cancer tumours, extracting DNA from a thymus gland (calf), and demonstrating pathogenic defects in genes by carrying out a polymerase chain reaction (PCR) and gel-electrophoresis. Combined with exploration and discussion of the relevance and complications of cancer research for patients, their relatives, and society, genomics was placed in a social and moral context.

A week after the lab-lessons, during the fourth lesson, the students were asked to reflect on their hands-on experiences. They had to draw conclusions from the experiments and to complete a fictional counsel form that laboratory researchers use to write down their findings and conclusions. The students were given the role of a researcher by having to give treatment recommendations to a doctor. They had to read "non-specialist" articles on SSI (breast cancer) in class and to reflect on their own questions formulated at the introductory lesson. There was room for ethical discussions, so the experiments could be placed in a broader, societal context and students could reflect on experiences, feelings, and thoughts.

The science module utilised several design principles, which can be derived from a social constructivist perspective on learning. The metaphor of participation is often used to characterise this concept of learning (Salomon & Perkins, 1998; Sfard, 1998). In essence, social constructivist educational theories interpret learning as increasingly competent participation in the discourse, norms, and practices associated with particular communities of practice (Lave & Wenger, 1991; Wenger, 1998). Becoming a more central participant in society is not just a matter of acquiring knowledge and skills. It also implies becoming a member of a community of practice. For this to happen, learning contexts must be chosen, so that students can make sense of the subject matter and hence give them a feeling of responsibility to participate critically in the practice in question.

Over the last decade, elements of social constructivist conceptions of learning have been used in science education (Frijters, Ten Dam, & Rijlaarsdam, 2008; Ogborn, 1997). In particular, the interest in how students learn to think critically about social issues increases (e.g. Driver et al., 2000; Kolstø, 2001; Sadler & Zeidler, 2005). Improving science education is interpreted as helping young people engaging with the social practice of scientists. Against the background of this social constructivist perspective on learning, we can describe the module "Read the language of the tumour" in terms of five design principles:

1. Stimulates active learning
2. Stimulates inquiry-based learning
3. Uses authentic tasks
4. Stimulates reflection
5. Uses socioscientific issues

Simulating active learning. Generally speaking, active learning is a process where students engage in higher-order thinking tasks such as analysis, synthesis, and evaluation. From a social constructivist point of view, the active role of learners is explicitly linked to the processes of making sense. Students are not seen as passive receivers of information, but as active interpreters of social meanings. Ogborn (1997) advocated learning arrangements in science education in which the learner is actively involved in the integration of new experiences and information into what he or she already knows. In the module, the active contribution of students was facilitated in several ways. Throughout the module, students were encouraged to formulate and ask their own questions about cancer and cancer research. In the brainstorm session (first lesson) they had to write down their own opinions and questions, discuss them in a small group, and afterwards within the context of a class discussion. Furthermore, active learning was stimulated by making use of authentic learning tasks (see subsequent paragraph 4).

Stimulating inquiry-based learning. According to Wells (1999), a class should function as a community of inquiry in which each student makes her or his own contribution. This social constructivist element is also present in science education research. A large number of studies have shown that inquiry-based science activities have positive effects on students' cognitive development, self-confidence, science achievement, attitude improvement towards both science and school, and conceptual understanding of science as a whole compared to a more conventional approach to science education (Butts, Koballa, & Elliott, 1997; Gibson & Chase, 2002; Jarrett, 1999; Zacharia, 2003). Rutherford (1993) stated that "hands-on and learning by inquiry are powerful ideas, and we know that engaging students actively (…) pays off in better learning" (p. 5). One of the building blocks of the module is the assumption that the actual performance of (genomics) techniques, combined with an exploration of the social and moral implications of cancer, can positively influence scientific literacy. The students were invited to learn through an inquiry-based and hands-on approach. Students learned about concepts of cancer, cancer research, and genomics by examining a real world, open-ended scenario and worked towards providing solutions that made sense to them.

Using authentic tasks. Authentic tasks resemble tasks performed in a non-educational setting (real-life tasks or activities) and require students to apply a broad range of knowledge and skills (Newmann & Wehlage, 1993; Roth, 1999). The tasks refer to complex situations, contain open-ended, ill-defined problems and often require a multidisciplinary approach as well as collaborative work (ten Berge, Ramaekers, Brinkkemper, & Pilot, 2005). Authentic tasks are believed to help students to become aware of the relevance and meaningfulness of what they are learning, because the tasks mirror real-life experiences and provoke active and constructive learning (Lowyck, 2005). Thus, besides developing knowledge, skills and attitudes, it is assumed that authentic tasks increase motivation (Herrington & Oliver, 2000). This makes authentic tasks particularly suitable for helping young people to engage with the social practice of scientists and stimulate scientific literacy. According to

Grabinger (1996), science and technology components should be looked upon from students' perspectives. In the module, authentic tasks were developed around the scientific concept of genomics using issues that are meaningful in students' lives (cf. Goodrum et al., 2001). The module was about cancer and cancer research, which provides a realistic and authentic context, as almost everyone has a relative who has dealt or is dealing with cancer.

Stimulating reflection. From a social constructivist perspective, education should aim at learning to participate in society in a critical and aware manner. Performing authentic tasks in itself does not necessarily result in such an outcome. Issues to be dealt with should be made explicit, for example through dialogue in the classroom. Dialogue is generally considered a powerful instrument for reflection (Wells, 2000). Several researchers have noted the important role of reflection as a learning activity in developing scientific literacy (Sadler & Zeidler, 2004; Zeidler, Sadler, Simmons, & Howes, 2005; Zeidler et al., 2002). By reflecting on thoughts, feelings and actions, students create a meaningful picture of their experience of the world, for which they will take responsibility. Empirical studies on effectiveness of science education state that science education should not only focus on knowledge and understanding, but also by reflecting on the affective and ethical side of biotechnology (e.g. Chiappetta, Sethna, & Fillman, 1991; Lee et al., 2003; Wilkinson, 1999). In this science module, in the final lesson, the students reflected on the hands-on experience by writing down their findings and conclusions. Moreover, they read articles in class and reflected on their own questions formulated during the introductory lesson. Throughout the module, the students were encouraged to engage in (ethical) discussions with their peers in order to reflect on their own experiences, feelings, and thoughts.

Using socioscientific issues. Finally, cancer and cancer research encompass SSI. Issues, such as cloning, stem cell research, genetic testing, and genetically modified foods will play a significant role in everyday life in the (near) future. These issues are not only of great importance to scientists; they will have great impact on the whole society and are therefore termed SSI (Kolstø, 2001; Zeidler et al., 2002). An important factor of scientific literacy is the ability to negotiate these SSI and make informed decisions regarding these issues (Sadler, 2002, 2004). In examining previous research on how these issues can be incorporated into science curricula and classroom practice, we found that most research has been done on students' reasoning about these complex issues with inherent social implications (see Sadler & Zeidler, 2005; Zeidler & Keefer, 2003; Zeidler et al., 2005). It has been suggested that SSI are taught most effectively through argumentation in the classroom (Conner, 2000; Steele & Aubusson, 2004). This requires subject matter that provides a meaningful, rich source of dilemmas for students to consider, such as cancer (Conner, 2000). The science module focused on several dilemmas of biotechnology relevant to the students' lives, such as family, lifestyle choices, preventive treatments, which were linked to knowledge of genetics in general as well as to biotechnology. The nature of the topic therefore provided students the opportunity to think about and discuss this SSI.

The five design principles described are derived from science education literature. The empirical basis, however, is rather weak. The research area is dominated by small-scale studies and there is a lack of experimental research in this area with regard to the effectiveness of the proposed design principles in classroom settings. The nature of most of the studies allows for limited conclusions regarding the possible effects of such a learning arrangement on attitudes. It remains unclear whether, for example, more critical attitudes towards biotechnology have been elicited, and whether they are based on a broader understanding. The combination of the design principles described here seems to promote scientific literacy, but more evidence is needed. The present study attempts to answer some of the questions left unanswered by performing a quasi-experimental study using the new Dutch science module “Read the language of the tumour”.

Research Question and Hypotheses

The main purpose of this study was to investigate the effects of the science module on the development of the attitudinal aspects of students’ scientific literacy towards modern biotechnology. As described before, the majority of students could be labelled as less scientifically literate on this particular field; a poor cognitive base combined with unclear opinions. The question was to what extent the science module could bring about more balanced and decisive attitudes.

The research question can be phrased as follows: What is the effect of a science module, utilising several design principles, related to a social constructivist perspective on learning, on attitudes of secondary school students towards modern biotechnology?

The following central hypothesis guided this study: *The science module has a more positive effect on the development of students’ attitudes than the regular science classes.*

If the module was successful, the low scientific literate group has enhanced their knowledge base, as well as their awareness of genomics. Consequently, they will either move to the group of “confident supporters” or become more critical in their opinion and move to the “concerned sceptics” group. More specifically, we expected to observe the following changes in the attitude post-test compared to the pre-test and the control group:

1. A smaller percentage of students in the “not sure” group
2. A smaller percentage of students in the “not for me” group
3. A larger percentage in the “confident supporter” group
4. A larger percentage in the “concerned sceptic” group

Apart from possible changes in group-membership, we will also examine what the effects of the science module were on the different factors in each of the three attitude components. For instance, can changes be detected in scores on biotechnology knowledge (in the cognitive component; see Table 1)? We implemented a pre-test–post-test experimental design to examine these hypotheses. The experimental condition consisted of students who besides their regular biology classes on genetics and biotechnology, participated in the science module. The control condition included students who did not partake in the science module, but only followed the regular biology curriculum on genetics and biotechnology.

Method

Participants

A total of 386 students (51.5% male) from 17 classrooms (year 11–12) from 10 secondary schools in the Netherlands participated in the study. Twenty-one respondents were excluded from further analysis because of incomplete pre- or post-test data, or outlier scores. Therefore, the total dataset included 365 respondents. The average age of the participating students was 16 years. Schools in the experimental condition were randomly selected from all schools participating in the DNA-lab project. Schools in the control condition were randomly selected from a general list of all Dutch secondary schools. In order to correct for possible effects of background variables, we selected schools that were comparable in terms of (1) the percentage of students with immigration and religious backgrounds, (2) students' socioeconomic background characteristics, and (3) the period in which the regular biology lessons on the subject of genetics was taught.

Research Design

Pre- and post-tests were administered to students in the experimental and the control condition. Table 2 illustrates the design of the study. Students in the experimental condition received practical workbooks with explanations, instructions, and assignments. Teachers received instruction manuals, including practical instructions and teaching guidance. Students in the control condition completed the pre- /or post-test, but did not participate in the science module. These students attended regular biology lessons on the subject of genetics, which includes lessons on modern biotechnology.

For reliability reasons (see the requirements), we made a distinction between three experimental groups and two control groups. Experimental group 1 (case study) differs from experimental group 2 in the sense that in this particular group of students, in addition to the administration of attitudes-pre-test and attitudes-post-test, interviews were held with selected students and classroom practice was observed.[2]

To determine the effects of the science module, the following requirements had to be met:[3]

1. The different groups of students needed to have the same starting point, as measured by the attitudes-pre-test.

Table 2. Design of the study

	Attitudes-pre-test	Experimental science module	Attitudes-post-test	Number of respondents[a]
Experimental groups				
Experimental group 1 (case study)	✓	✓	✓	75 (4 groups)
Experimental group 2	✓	✓	✓	100 (4 groups)
Experimental group 3	—	✓	✓	38 (2 groups)
Control groups				
Control group 1	✓	—	—	88 (4 groups)
Control group 2[b]	—	—	✓	64 (3 groups)

[a]Numbers of respondents can vary between pre- and post-test, as some students did not complete both questionnaires.

[b]As seen in the "requirements" section, control group 2 is not significantly different from control group 1. For this reason, both control groups can be considered as one group.

The results of the Chi-square test showed that there was no statistically significant difference between the pre-test scores for all experimental and control.

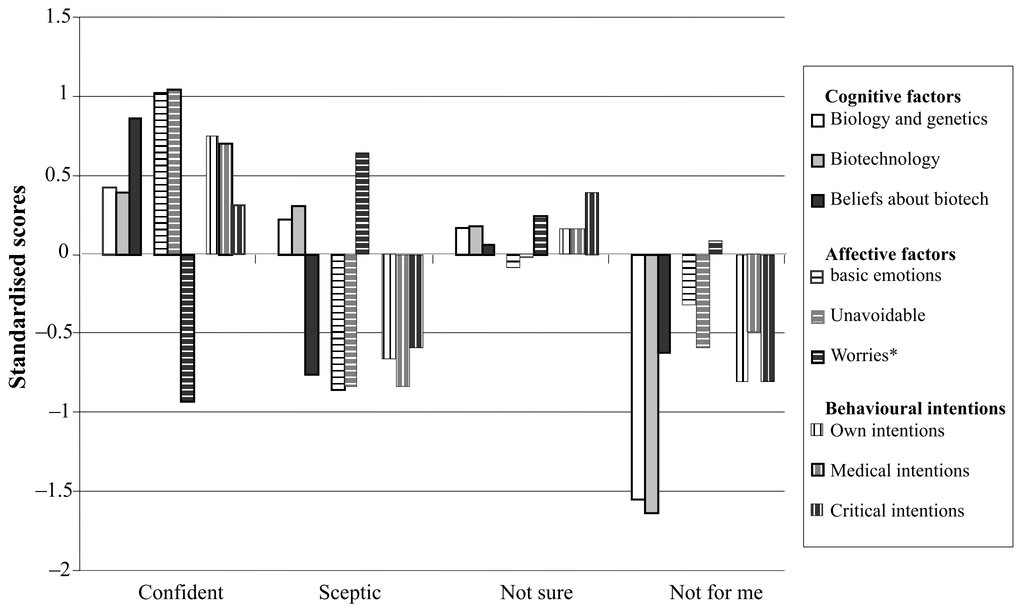
2. The possible impact of the attitudes-pre-test experience on learning during the module, and consequently on the attitudes-post-test needed to be ruled out.
   Therefore, we compared the post-test scores of the experimental group 2 (pre-test, treatment, and post-test) and the experimental group 3 (no pre-test, treatment and post-test).The results showed there was no statistically significant difference between these two groups.
3. The possible intervention effect due to the researcher's presence in the case study classes should be accounted for.
   To exclude this possibility, we performed a Chi-square test comparing the post-tests of the case study group (experimental group 1) and the post-test of the experimental group 2. The results showed no significant differences between these two different groups.
4. External incidents that affect the post-test should also be considered. For example, if geneticists found a cure for cancer by genetically modifying cells, during the time of the science classes, it may affect students' attitudes towards genomics and override the effect of the science module.
   For that reason, we analysed the results of the pre-test of control group 1 with the post-test of control group 2. No statistically significant difference could be established between these two control groups.

Analyses showed that all requirements were met. Therefore, we conclude that differences between conditions, and between pre- and post-test, cannot be ascribed to design effects.

Instrument

To measure students' attitudes towards biotechnology, we used a previously developed questionnaire, based on the general tripartite theory of attitudes (see Klop & Severiens, 2007).

The first section of the instrument was designed to obtain (socio-) demographic information about the students (only in pre-test). The second and third parts of the instrument included four categories of items: knowledge items, cognitive evaluation items (beliefs), affective evaluation items, and behavioural intention items (see Table 1, and we refer to Klop & Severiens [2007] for a detailed description of the development of the instrument). Based on principal component analyses, several distinct and independent cognitive, affective, and behavioural factors were found, as described in Table 1. Cluster analysis resulted in the four different attitudes as described previously: "confident supporter", "concerned sceptic", "not sure", and "not for me" (see Figure 1).



*Negative score on "worries factor" indicates fewer worries about modern biotechnology.

Figure 1. K-means cluster analysis of the attitude pre-test scores of 327 secondary school students, combined with the dataset of the previous attitude test scores.[4] "Confident supporters" (n = 113), "concerned sceptics" (n = 66), "not sures" (n = 123), and "not for me"s (n = 25). Scores are standardised values

Analyses

To check the central hypothesis of the study, cluster-membership of students in the pre-test were compared to cluster-membership in the post-test, and experimental groups were compared to control groups. Because of the nominal measurement level of the dependent variable (cluster-membership), the comparison is done using Chi-square tests. This test compares the distribution of students before the module to the distribution after the module, as well as possible significant differences between the experimental and control condition.

Results

The results of the comparison of the experimental groups with the control groups are presented first. Secondly, the results regarding the post-test compared with the pre-test within the experimental groups are described. We conclude this section with an analysis of the changes concerning the attitude components.

Comparison Experimental Groups and Control Groups

Using a Chi-square test, the post-tests of the experimental groups (1, 2, and 3) and the post-test of the control groups (which received no treatment) were compared. A significant difference of distribution of students in the four attitude-clusters was found between the experimental and control groups in the post-test-scores χ^2 (3, N = 348) = 9.53, $p < .05$ (see Table 3). The largest differences could be found in the percentage of "confident students" in the experimental group versus those in the control group (43.9% versus 30.3%) and between the "not sure students" in the experimental group and the "not sure's" in the control group (40.3% vs. 46.1%) (Table 3).

The first three hypotheses can be confirmed: (1) At the end of the science module, there were significantly more students in the "confident" group; (2) less students in the "not for me" group, compared to the control group; and (3) The percentage of students in the "not sure" group was somewhat smaller in the experimental groups (40.3% versus 46.1%). The fourth hypothesis, that there would be more students in the "sceptic" group, could not be confirmed. There were even somewhat more sceptics in the control condition (14.3% versus 18.4%).

Table 3. Result of Chi-square test for comparison between post-test scores of experimental groups and post-test scores of control groups

		Clusters post-test				
		Confident (*n*)	Sceptic (*n*)	Not sure (*n*)	Not for me (*n*)	Total (*n*)
Experimental condition	Treatment	43.9% (86)	14.3% (28)	40.3% (79)	1.5% (3)	100% (196)
Control condition	No treatment	30.3% (46)	18.4% (28)	46.1% (70)	5.3% (8)	100% (152)

Note. Chi-square = 9.53; df = 3; asymp. sig. (two-sided) $p < .05$.

Comparison of Pre- and Post-Tests within Experimental Condition

A comparison was made between "attitude-cluster membership" before and after the science module within experimental groups. This comparison shows the possible changes in distribution of students over the four attitude-clusters. Table 4 presents the results of the Chi-square analyses, showing whether shifts in the distribution are statistically significant.

We hypothesised a decrease of students in the "not sure" group. In the pre-test, 35.1% of students belonged to the "not sure" group. In the post-test, this group has grown slightly to 37.1%. Therefore, the first hypothesis must be rejected. The majority of this 37.1% belonged to the same cluster at the pre-test (41.1%, see the column percentages in Table 4), but a considerable percentage originated from the "concerned sceptic" cluster (26.8%). Another part of the post-test "not sure" cluster consisted of students who initially belonged to the "confident supporter" (21.4%) and "not for me" groups (10.7%).

The second hypothesis, a smaller percentage of students in the "not for me" group, can be confirmed. There was a decline of 6.0% in the pre-test to 2.0% in the post-test. Of the three students in the "not for me" group, two started out as a "not for me" student, and one from the "not sure" group (see Table 4).

According to hypothesis 3, the percentage of students in the "confident supporter" group should increase. The group of "confident supporters" increased from 39.1% in the pre-test to 48.3% in the post-test. Hypothesis 3 can therefore be confirmed. Sixty-three percent already belonged to this cluster at the start of the module and 31.5% initially belonged to the "not sure" cluster, 4.1% were "concerned sceptics" and 1.4% "not for me"s (see Table 4).

Finally, hypothesis 4 must be rejected. A higher percentage of students in the "concerned sceptic" group was not observed. The percentage of students in this group even decreased from 19.9% to 12.6%. More than half of them remained sceptics (63.3%). The other 36.7% consisted mostly out of students who initially belonged to the "not sure" group (31.6%) and a small part of "confidents" (5.3%) (see Table 4).

Effect of Science Module on Attitude Components

A remarkable result from the analyses comparing pre- and post-tests, concerns the increase of the "not sure" cluster. Contrary to our expectations, a reasonable number of "sceptics" as well as "confidents" ended up not being sure what to think of modern biotechnology anymore. Does this result indicate a decrease in scientific literacy?

We examined what the effects of the science module were on the different attitude factors, by conducting pairwise *t*-tests on each of the attitude factors (see Table 2 for a description of all factors). First, we examined the attitudinal changes of the entire experimental group, and subsequently of the post-"not sure" group. With this, we examined in more detail why students changed from being confident or sceptical to being unsure. The results are shown in Table 5.

Table 4. Result of Chi-square test for comparison of cluster distribution of the students based on pre- and post-test scores of experimental groups

Cluster pre-test	Cluster post-test				
	Confident	Sceptic	Not sure	Not for me	Total
Confident					
Count	46	1	12	0	59
% within cluster at post-test	63.0	5.3	21.4	0.0	
% of total	30.5	0.7	7.9	0.0	39.1
Sceptic					
Count	3	12	15	0	30
% within cluster at post-test	4.1	63.2	26.8	0.0	
% of total	2.0	7.9	9.9	0.0	19.9
Not sure					
Count	23	6	23	1	53
% within cluster at post-test	31.5	31.6	41.1	33.3	
% of total	15.2	4.0	15.2	0.7	35.1
Not for me					
Count	1	0	6	2	9
% within cluster at post-test	1.4	0.0	10.7	66.7	
% of total	0.7	0.0	4.0	1.3	6.0
Total					
Count	73	19	56	3	151
% within cluster at post-test	100	100	100	100	
% of total	48.3	12.6	37.1	2.0	100

Note. Chi-square = 76.19; df = 9; asymp. sig. (two-sided) $p < .00$.

The results comparing the mean pre-test score to the mean post-test score of the students in the experimental condition revealed an overall significant improvement on two of the three factors measuring the cognitive component; knowledge of biotechnological applications, $t(150) = -2.90$, $p < .001$, and beliefs, $t(150) = -3.01$, $p < .001$. There was also an increase in average scores on two of the three factors that measured the affective component: unavoidable, $t(150) = -3.01$, $p < .001$ and worries, $t(150) = 3.00$, $p < .001$ (reversely coded, see Table 5). These results suggest that the students showed a significant improvement in scientific literacy in terms of their knowledge base and positive awareness of genomics. However, no significant movement towards a more critical stance could be established, explaining the rejection of the fourth hypothesis (a larger percentage in the "concerned sceptics" group).

Secondly, *t*-tests were used to detect the mean differences between pre- and post-test scores of the final "not sure" students, coming from the other three attitude-clusters.

For the "confident supporters" turning into "not sure"s, there was a significant effect for the behavioural factors. The students showed less intentions of consuming

Table 5. Mean attitude component scores for all participants on the experimental condition, obtained *t*-test, and significance of differences following paired sample analyses

Attitude factors		Paired differences				
		Mean difference	SD	*t*	df	Sig. (two-tailed)
Pair 1	Biological and genetic pre–biological and genetic post	−.00	.3	−0.33	150	.75
Pair 2	Biotechnology pre–biotechnology post	−.03	.11	−2.90	150	.00
Pair 3	Beliefs pre–beliefs post	−.13	.55	−3.01	150	.00
Pair 4	Basic emotion pre–basic emotion post	.05	.47	1.26	150	.21
Pair 5	Unavoidable pre–unavoidable post	−.13	.51	−3.01	150	.00
Pair 6	Worries pre–worries post	.17	.68	3.00	150	.00
Pair 7	Own intention pre–own intention post	−.07	.66	−1.21	150	.23
Pair 8	Medical intention pre–medical intention post	−.01	.72	−0.14	150	.89
Pair 9	Critical intention pre–critical intention post	−.06	.67	−1.05	150	.30

when there is a personal benefit to gain (own intentions), $t(11) = 2.39$, $p < .05$. The intentions of using medical applications, such as genetic tests also declined, $t(11) = 2.22$, $p < .05$, and consuming intention under critical or environmental conditions (e.g. environmentally friendlier) also declined, $t(11) = 2.28$, $p < .05$. Apparently, a more reserved position towards behavioural intentions made these students change into "not sure"s.

A clear shift in affection was observed in the "concerned sceptic" group. The expressed worries towards biotechnology reduced, $t(14) = 4.04$, $p < .001$ (reversely coded), and feelings of biotechnology as an unavoidable process became stronger, $t(14) = -3.51$, $p < .001$. The post-sceptics also showed a more positive stance towards behavioural intentions, except for medical intentions (own intention, $t(14) = -2.16$, $p \leq .05$; critical intentions, $t(14) = -2.43$, $p < .05$). Apparently, with a more positive affective and intentional standpoint, these students lost a little of their concern and scepticism, and consequently moved to the "not sure" group.

As far as the "not for me"s are concerned, a significant improvement on the scales measuring the cognitive component was observed. There was a significant progress on content knowledge of biotechnology and its applications, $t(5) = -4.45$, $p < .05$, and a more positive beliefs towards modern biotechnology, $t(5) = -2.80$, $p < .05$. By changing into "not sure"s, this group was still not able to make up their mind completely, but did show a more solid cognitive base.

Discussion

Being scientific literate means understanding the world we live in and being interested in it, taking part in discussions of and about science, and being sceptical and questioning claims made by others about scientific matters so that we can make informed decisions about the environment and personal health and well-being (Goodrum et al., 2001). In our view, and as far as modern biotechnology is concerned, scientifically literate people have an accurate knowledge base on basic biological and genetic concepts, display an affective reaction of concern or comfort towards biotechnology issues, and have clear ideas on how to behave or make decisions when confronted with modern biotechnology (in accordance with Millar, 2006); in other words, having a well-considered confident or sceptical attitude towards modern biotechnology (Klop & Severiens, 2007). The question is how can students' attitudes towards modern biotechnology become more articulate through education? In what ways can science modules encourage students to learn about so-called SSI and develop their own soundly based attitudes?

This study examined the effects of an innovative science module on the attitudes of secondary school students towards modern biotechnology. We made use of a new Dutch science module for the upper levels of secondary education. The socioscientific topic of the science module was genomics and cancer, the underlying design principles, inspired by a social constructivist perspective on learning. We hypothesised that if the module was successful in developing attitudes, more students would move to the group of "confident supporters" or become more critical in their opinion and shift to the "concerned sceptics" group, and consequently, fewer students would be found in the "not sure" or "not for me" clusters.

Based on the combination of design principles and the socioscientific and relatively new subject matter (Conner, 2000; Sadler, 2002; Zeidler et al., 2005), we had reason to believe that even a small module could bring about some changes in attitudes.

Changes were indeed observed and our hypotheses were partly confirmed. The module did result in a larger group of "confident supporters", also in comparison with the control condition. The expected increase in the numbers of "concerned sceptics" was, however, not observed. The "sceptic" group even decreased in size. We offer three explanations for this finding. The first explanation concerns the number of lessons in the module: The changes were brought about in only four lessons. Students might have been overwhelmed by the (in particular "pro-genomics", see next paragraph) module and as a consequence adopted ways of thinking about modern biotechnology without having time to think critically about its construct.

Elaborating on this first explanation, we give a second reason for the growth in the "confident supporter" group, and the reduction in the "concerned sceptic" group. There may have been a possible overexposure of the positive sides of modern biotechnology during the lessons. Although some critical references on societal issues were offered in the workbook of the students, the emphasis of the module was on the benefits of cancer research using biotechnology. For that reason, the likelihood of students changing into "a confident supporter" is greater than the likelihood of them turning into "concerned sceptics". From the perspective of biotechnological research institutions or universities, this might be seen as a positive side effect, but it is certainly not the purpose of teaching for scientific literacy. Therefore, we would like to argue that in the interest of fostering scientific literacy among students, science education modules such as the one described in the present study should focus on all aspects of genomics, the advantages as well as the disadvantages, the technical as well as the ethical.

A third explanation for the decrease in the "concerned sceptic" group might be the quality of the fourth lesson of the module. Observation data gathered during the science module, and other research on this science module suggested that many teachers omitted (most of the) reflection activities (see Knippels, van der Rijst, & Severiens, 2006, for a general evaluation of the science module; Waarlo, 2007). This means that a relatively large group of students was not invited to think critically about their newly acquired knowledge and feelings and the discussions they had had with their peers on the subject. These are, however, important factors in developing scientific literacy (Sadler & Zeidler, 2004; Zeidler et al., 2002, 2005). There is relatively little attention devoted to reflection on the learning content (deep understanding and insight) and reflection on students' own thinking and learning processes (meta-cognition) in most subjects in secondary education (Volman & Ten Dam, 2000). These explanations lead to a recommendation for improving the science module: If there is more time spent, and a greater emphasis placed on reflection activities, it may help students to move from the "not sure" group to the "sceptics" group.

An unexpected finding in the present study concerned the substantial group of the students that moved from the "confident supporter" group, or the "concerned sceptic" group, to the "not sure" group. Our previous study has demonstrated that this particular group of students has a rather undefined attitude towards modern biotechnology; they are not sure what to think, feel, or do with it and their overall knowledge of the subject is rather poor. This may be a perfectly understandable position of "the average teenager", and we expected that the science module would give them a more solid foundation to base their attitudes on, and that they would demonstrate more certainty about their own opinion. T-test analyses showed that this partially occurred. All students in the experimental condition showed a significant improvement on the cognitive and affective component, as far as their knowledge base and positive awareness of genomics goes. This also implies that the meaning of "being not sure" after the module has changed, especially since several "confident supporters" and "concerned sceptics" made a transition towards "not sure". During the science module, students acquired new knowledge, learned about new dilemmas, discussed these dilemmas with peers, and did hands-on work that was supervised by interesting students from a university, and so forth. In hindsight, it is understandable that due to all these experiences, and the increase in their knowledge level, some of these students have started questioning their own views and behavioural intentions. In that sense, these students have become "less sure" about what to think. In our instrument, we made no (quantitative) distinction between ambivalent or questioning responses from indifferent responses (Gardner, 1987). Future research should therefore include a measure of ambivalence.

Another suggestion for future research would be the design of a long-term effect study. In this study, the time in between attitudes-pre-test and attitudes-post-test to follow students' attitudinal changes was approximately one to one and a half months. What is the persistence of the effects? What happened with the changes in attitudes in, for instance, six months time? Have the effects vanished or maybe intensified? This will provide not only valuable information about the effectiveness of science education, but also about the durability of attitude changes.

In summary, we have suggested that the science module could help secondary school students become more articulate in their attitudes towards modern biotechnology. The expectation was that the module would help secondary school students develop a more pronounced attitude towards modern biotechnology. The science module indeed helped students to become somewhat more scientific literate by the improvement of their knowledge base and display of affective reactions towards biotechnology issues. Nevertheless, students were insufficiently invited to think critically about their newly acquired knowledge, feelings, and the discussions on the subjects that went on in the classrooms. This resulted in an under-representation of critical and sceptic students at the end. Besides, when SSI are discussed only one-sidedly, for example, by leaving out the ethical dilemmas, again students are not invited to take a critical stance.

All students must be aware of the complexity of this expanding scientific discipline, so they will be able to participate, to be sceptical and questioning about scientific matters, and to make informed decisions for personal, social, and global benefit.

Acknowledgements

The study described in this article was financially supported by the Dutch Research Organisation (NWO), in particular by the programme Societal and Ethical Aspects of Genomics (MCG-programme).

Notes

1. The Cancer Genomics Centre (CGC) is a strategic collaboration of research groups from the Netherlands Cancer Institute, the Erasmus Medical Center, the Hubrecht Laboratory and the University Medical Centre, Utrecht.
2. The interview and observations are described in a subsequent article of a qualitative nature.
3. Results of Chi-square test for comparison between (scores of) experimental and control groups are available from the authors if needed.
4. Cluster analyses on the data of the pre-tests showed slightly different clusters compared to the results in our former study, due to different background characteristics of the current dataset. Because our former study (Klop & Severiens, 2007) was based on a representative sample of students in terms of levels of education, and the present study was based on the pre-higher education tracks only, the clusters as observed in the former study serve as a starting point for the present study. To maintain this particular composition, we combined the current dataset with the dataset of the previous study and performed cluster analyses on this larger dataset. These analyses did result in the four originally observed clusters (Figure 1). In this way, the students in the present study are appointed to one of the four original clusters.

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