Teaching Controversial Socio-Scientific Issues in Biology and Geology Classes: A Case Study

Pedro Reis
Universidade de Lisboa, Portugal

Cecília Galvão
Universidade de Lisboa, Portugal

Abstract

Several educators in science have called for the inclusion of controversial socio-scientific issues' discussion in science curricula because of its potential for creating a more real, humane image of scientific activity and for promoting scientific literacy, an essential tool for a responsible citizenship regarding decision-making processes related to socio-scientific issues. However, despite all the favourable opinions and empirical evidence concerning the educational potential for the discussion of socio-scientific issues, these activities are not part of many science lessons, even when the controversial socio-scientific issues comprise the curricular content and the teachers consider discussion of these issues important.

This qualitative investigation, based on a case study centered on a Biology and Geology teacher, aimed to understand the factors that influence positively the conduction of discussion activities regarding controversial socio-scientific issues. By analysing data from interviews and class observations, it sought to understand the factors that motivate the teacher to implement this type of activity.

This case study shows that the implementation of the discussion activities about controversial socio-scientific issues depends decisively on the teacher's convictions about the educational relevance of these activities and the knowledge needed for their design, management and assessment. The development of these competences was triggered by professional development opportunities in which the teacher experienced new approaches under experts' supervision.

Correspondence should be addressed to Pedro Reis at PedroRochaReis@netcabo.pt, or Cecília Galvão at cgalvao@fc.ul.pt

Introduction

This investigation belongs to a series of studies and interventions aimed at supporting the implementation, in Portugal, of new science curricula, that call for the discussion of controversial socio-scientific issues as a way of preparing students for an active, informed participation in society (Reis, 1997, 2004; Reis and Galvão, 2004a, 2005). These studies intend to understand the factors that influence both positively and negatively the conduction of science class discussion activities regarding controversial socio-scientific issues and, based on this knowledge, to conceive and implement intervention processes capable of providing teachers with the confidence, motivation and knowledge required to use activities of this nature. Accordingly to Cowie and Rudduck (1990), discussion-based "practice is immensely varied but can be roughly sorted into three broad approaches: the discussion of controversial issues; problem solving; and role-play" (p. 807). All these approaches seek to promote learning through the exploration and expression of ideas, opinions and experiences in an environment of collaboration where the discussion is not seen as verbal combat: it is not a question of winning an argument but a process of mobilizing the entire group resources with the aim of increasing knowledge, understanding a given subject or solving a problem.

The controversial socio-scientific issues referred to in this study consist of matters related to interactions between science, technology and society (namely the controversies that arise because of possible social impacts of scientific and technological novelties) that divide both the scientific community and society at large and for which different groups of citizens put forth explanations and attempts to find solutions that are incompatible, based on alternative beliefs, understandings and values (Crick, 1998; Kumar and Chubin, 2000; Oulton, Dillon and Grace, 2004; Rudduck, 1986; Yager, 1992). The controversial dimension refers to "differences over the nature and content of the science such as the perception of risk, interpretation of empirical data and scientific theories, as well as the social impact of science and technology" (Levinson, 2006, p. 1202). These socio-scientific issues are of a contentious nature; they may be analysed according to different perspectives, they do not lead to simple conclusions and often they involve a moral, ethical dimension (Sadler and Zeidler, 2004).

Theoretical Background

The media confronts citizens almost daily with news about scientific issues with controversial social by-products: cloning; the use of stem cells in medical research and therapy; the release into the atmosphere of substances that are harmful for public health, for the greenhouse effect and that reduce the ozone layer; the use of hormones and antibiotics in animal production. This kind of news introduces citizens to a different type of science from the one that is usually presented in science classes. Most formal science education focuses on a conventional, non-controversial, established and reliable science and doesn't discuss its tentative nature while the media's news highlights a "borderline science", that is controversial, preliminary and under debate (Zimmerman, Bisanz and Bisanz, 1999). Therefore, media's news may threaten the conception, shared by many people, of scientific development as a linear process of mere knowledge accumulation, with no crisis, confrontation or controversy. They may threaten also the common conception of science as a socially neutral activity, that ignores the complex relations between science, technology and society and the social, economic, political, moral and environmental implications of scientific and technological knowledge (Reis and Galvão, 2004b).

Nowadays, the media (newspapers, magazines, television, radio and the Internet), taken as a whole, are considered "the most easily accessible sources of science information to the general public" (Lewenstein, 2001, p. 30). Nelkin (1995) declares that: "For most people, the reality of science is what they read in the press. They understand science less through direct experience or past education than through the filter of journalistic language and imagery" (p. 2). In her opinion, the media represent the only contact most of the population has with the rapidly changing fields of science and technology, as well as a major source of information on the social implications of these changes. Even citizens with a scientific or technological career are incapable of following the specialized literature of all scientific fields, resorting to the media to stay informed about scientific progress outside their speciality (Bauer, 1992). However, sometimes the media present a sensationalist image lacking in rigor and stereotyping science and scientists (Nelkin, 1995). Many fiction films describe scientific investigation as an activity that crosses the borders of the admissible, violating human nature and pursuing the quest for new knowledge in secrecy and outside the controls of society (Weingart, Muhl and Pansegrau, 2003). From medieval stories about alchemists to modern films about cloning, the narratives about scientists rarely depict them in a positive way, translating the fear of the power and change that are part of science and resorting to a limited number of stereotypes: the diabolical alchemist; the heroic scientist, saviour of society; the mad scientist; the inhumane, insensitive researcher; the adventurer scientist who transcends frontiers of space and time; the mad, mean, dangerous, unscrupulous scientist exercising power; and the scientist who is incapable of controlling the results of his work (Haynes, 2003). There is empirical evidence that the use of metaphors of great impact in addressing socio-scientific issues (namely in the field of biotechnology, molecular genetics and medical sciences) and in the description of scientists' activity affects the population's trust and conceptions regarding science and, subsequently, the way citizens understand, think about and act upon socio-scientific issues (Liakopoulos, 2002).

All those media influences stress the need that schools promote the discussion of socio-scientific issues and, consequently, the discussion of students' conceptions about these issues and about the interactions between science, technology and society. Conceptions are a fundamental foundation of thinking and acting, providing the means to see the world and organise concepts (Thompson, 1992).

Several educators in science have called for the inclusion of socio-scientific issues' discussion in science curricula because of its potential for creating a more real, humane image of scientific activity and for promoting scientific literacy, an essential tool for a responsible citizenship regarding decision-making processes related to socio-scientific issues (Kolstoe, 2001; Millar and Hunt, 2002; Millar and Osborne, 1998; Monk and Dillon, 2000). They argue that in a democratic society, the public evaluation of science requires the participation and involvement of as many citizens as possible, and this is only possible by understanding what science is and how it is produced. At the same time, several authors claim that the discussion of socio-scientific issues in the classroom has shown to be extremely useful both in terms of learning about the contents, the processes and the nature of science and technology, and in terms of the students' cognitive, social, political, moral and ethical development (Hammerich, 2000; Kolstoe, 2001; Millar, 1997; Reis, 1997; Reis, 2004; Sadler, 2004).

However, the discussion of socio-scientific issues is an uncommon practice in science classes. Some teachers avoid discussing these issues for fear of protests by the students' parents and a possible lack of control during the discussions (Stradling, 1984). Many teachers lack management skills related to classroom discussions and the required knowledge to undertake discussions about socio-scientific issues, namely knowledge about the nature of science and the sociological, political, ethical and economic aspects of the issues at stake (Levinson, 2001, 2004; Levinson and Turner, 2001; Newton, 1999; Reis, 2004; Reis and Galvão, 2004a, 2005; Simmons and Zeidler, 2003; Stradling, 1984). Other teachers feel the restraints imposed by the excessive number of topics in science curricula (Levinson and Turner, 2001; Reis and Galvão, 2004a) or by national evaluation systems that do not value this type of discussion activity (McGinnis and Simmons, 1999; Newton, 1999; Reis, 2004; Reis and Galvão, 2004a). It is also true that many science teachers view science as an objective enterprise free from values. These science teachers see their task as teaching the facts (and not discussing opinions or ethical aspects), shifting the onus for discussion of the social, moral and ethical implications of science and technology to the lessons of their humanities colleagues (Levinson, 2001; Levinson and Turner, 2001). When ethical questions are introduced into the science classroom, they are treated as an initial starting point and presented briefly with little analysis or criticism. All these facts stress the importance and relevance of studying the factors that influence the implementation of discussion activities regarding controversial issues in science classes, whether positively or negatively. Identifying and understanding these factors is decisive for the conception and implementation of intervention processes that help teachers overcome these restraints and support them in planning and carrying out such activities.

Problem and Methodology

This qualitative investigation is based on a case study centred on an 11th grade Biology and Geology teacher from a secondary school in Lisbon area. It aims to understand the factors that influence positively the conduction of science class discussion activities regarding controversial socio-scientific issues. This investigation intended also to study the meaning attributed by the teacher to recent socio-scientific issues, made public by the media, as well as the importance given to the discussion of these controversial issues in her classroom.

The teacher was selected, from a group that had already collaborated with the researchers on previous studies, as a result of her long experience dealing with the discussion of controversial socio-scientific issues in classroom context. The choice of the 11th grade "Biology and Geology" subject resulted from the fact that in a previous study (Reis and Galvão, 2004a) it was considered, by the teachers, one of the most suitable subjects for carrying out discussion activities regarding socio-scientific issues, given the content of the program topics (e.g. genetics and human reproduction) and the students' ages (17 years old). The teacher's name was replaced with a fictitious one in order to preserve her privacy.

Over one school year, the work developed by this teacher in one of her "Biology and Geology" classes was closely followed. Different information was gathered through semi-structured interviews and direct observation of classes. It is important to underline that the teacher was not aware of the reasons underlying the observation of these specific classes or of the specific aims of the study: the investigators only informed her that they intended to study the teaching of “Biology and Geology” subject. In this manner, she was not induced into choosing a certain classroom methodology or strategy. The main objective of the semi-structured interviews was to collect opinions in the subject’s own language, allowing the researchers to intuitively create an idea of the subject’s conceptions on current controversies related to scientific and technological issues and on Biology and Geology teaching and learning. Throughout the study three semi-structured interviews were carried out. The first interview (TI1) took place at the start of the school year and sought to gather evidence about the teacher’s conceptions regarding: a) the nature of scientific and technological knowledge; b) Biology and Geology teaching and learning; and c) recent controversial issues related to science and technology. Its content (developed in a previous study: Reis and Galvão, 2004a) included questions regarding the following dimensions: Professional experience; Attended professional development initiatives on effective methods of engaging students in STS issues; Characteristics of the context where she teaches; Self-concept as a Natural Science teacher; Conceptions about teaching and learning; Conceptions about the nature of science and technology; and Conceptions about controversial issues related to science and technology. The second interview (TI2) was conducted shortly before the observation of a set of classes (14 periods of 50 minutes each) and aimed at promoting a discussion with the teacher about the intent of her observed lessons (Appendix 1). The third interview (TI3) was carried out after the classes and intended to promote reflection about its implementation (results reached, difficulties, successes, etc.). This last interview was based on a sequence of questions (Appendix 2), aimed at promoting the evaluation of the observed classes by the teacher. All the interviews were audio-taped which allowed the researchers to have a record for later transcription and analysis of the entire interview content.

The observation provided direct access to the classrooms, to find out how the teacher behaved in that specific context. Field notes were taken. During the investigation, a sequence of classes, planned and implemented by the participating teacher, was observed by one of the researchers. This sequence, that included 14 classes (of 50 minutes each), focused on topics (mitosis, meiosis and asexual and sexual reproduction) which the teacher considered (during interview TI1) appropriate to address socio-scientific issues such as cloning or genetic engineering. The observation was designed to analyze activities used by the teacher in addressing these topics and to find out whether (and how) she makes use of the discussion of socio-scientific issues. The combined use of observation and interviews provided a substantial amount of information about the way this teacher thinks and acts, and allowed the researchers to find out whether the interviewee’s descriptions (from the interviews) refer to the reality in her classes or to general perceptions of what a good practice should consist of.

The observation did not follow a strict observation schedule. However, special attention was paid to implemented activities, social interactions and students’ engagement level (notes were taken in relation to these aspects). The time spent on each classroom activity was recorded. The investigator adopted the role of direct, non-participant observer.

Transcripts of interviews and field notes were subjected to content analysis through a model of analytical induction (Bogdan and Biklen, 1992), which sought to extract the implicit conceptions about several aspects under study. This kind of analysis involves the classification of meaningful elements, according to certain categories that may bring order to the apparent disorder of the raw data. The category construction process, although essentially intuitive, is influenced by several aspects such as the aims and theoretical background of the study, as well as the researchers' conceptions and knowledge.

Initially, all data were analyzed separately by each researcher trying to identify teacher's conceptions about (1) teaching and learning, (2) the nature of science and technology, (3) controversial issues related to science and technology, (4) the discussion of controversial socio-scientific issues as classroom methodology. The analysis focused also on possible reasons for those conceptions. Following this, the results of the analysis were discussed not only by the two researchers, but also by two other colleagues of the same research centre. The different interpretations and few discrepancies that emerged during the classification process were discussed and resolved by agreement between all four researchers.

Cristina's Case

Cristina has been a Biology and Geology teacher for thirty-three years. She claims to like teaching so much that she "could never have chosen anything else".

After finishing her degree in Biological Sciences at Lisbon University and the practicum, she taught in several regions of Portugal. However, in the past twenty-two years she has worked at a secondary school in Lisbon area.

Her discourse and her work reveal an extremely dynamic, hard-working teacher who enjoys her professional activity tremendously: "What I most like to do is to teach. Therefore, coming into contact with students is the most important thing." (TI1) Throughout her professional life she taught all the Biology and Geology subjects of Basic and Secondary Education curricula and was a practicum supervisor, co-author of four textbooks, department coordinator and responsible for several projects and clubs in the fields of the Environment, Health and Sexuality.

In spite of all her professional life accomplishments, Cristina highlights the internship year and the teaching inservice opportunities she attended at the Calouste Gulbenkian Foundation (three years after working as a teacher) as the most important moments of her professional activity:

> *"(...)* [The internship supervisor] *was a wonderful person and an excellent teacher, I learned a lot from her. (...) We did a lot of practical work; I really enjoyed working that way. (...) We did brilliant things in the internship year."* (TI1)

> *"(...) the Gulbenkian courses* [attended during the holidays] *were an eye-opener in terms of ideas. (...) We stopped 'counting spider legs' and began to look at*

> *Biology differently. We began to use active methodologies (...) and to introduce discussion into the classroom."* (TI3)

She admits that both the internship and the abovementioned courses for Biology teachers were decisive in changing her teaching style, especially as regards the diversification of teaching strategies and the development of the didactic knowledge required for their use in the classroom.

Cristina argues that professional development opportunities only have impact when they involve the teachers in experiencing and discussing the new approaches and methods: "Experiencing is vital. Teachers only change their classroom practices when they personally experience the educational benefits of a specific method or approach" (TI3). Otherwise, in her opinion, the teachers end up implementing the kind of expository lessons they have undergone throughout their schooling. Both during her internship and the Calouste Gulbenkian Foundation courses, Cristina had the opportunity to experience new approaches under the supervision of experts. These opportunities were the catalysts of big changes in her classroom practice. During the internship she developed the necessary competences for planning and implementing practical work with her students, stressing the idea of science as a process. The Calouste Gulbenkian Foundation courses, attended during the summer holidays of three consecutive years, allowed Cristina to discuss Science, Technology and Society (STS) interactions an to experience discussion, role-play, simulation and decision-making activities as a way to have students acquire real understanding of STS interactions and the decision making processes related with science and technology issues. Through the rest of her career she continue to develop competencies in these areas, mainly through the classroom implementation of approaches and activities collected in science education journals and books (TI2).

Conceptions about Scientific and Technological Knowledge

During the first interview Cristina described science as a dynamic process in constant evolution that leads to the exponential growth of knowledge through the discussion of different ideas. Like some authors, she considers addressing aspects of the history of science in classes – namely the evolution of certain scientific concepts – is important to convey an image of science in constant construction (Matthews, 1994; Ziman, 1994). In her opinion, scientific enterprise establishes subtle, multiple interactions with technology and with society, by determining the evolution of technology, affecting citizens' lives and reacting to pressures from society. In her classes, she seeks to present students with this intricate web of influences and the notion that "scientific knowledge changes over time". In her opinion, science has a tentative nature, always adapting to new data and ideas.

Cristina considers science and technology to be complex human enterprises that engender different opinions among their agents, resulting from different beliefs and values. In her opinion, controversial socio-scientific issues cannot be solved simply on a technical basis because they involve other aspects: hierarchies of values, personal conveniences, financial matters, social pressures, and so on. She refers to genetic engineering, the use of human embryos in research, cloning and *in vitro* fertilisation as good examples of scientific or technological issues marked by controversy. The teacher supports the undertaking of research in these fields because of their potential to improve the quality of life of Humankind. However, she warns that scientists' motivations often seem far from noble and that sometimes their ambition comes before their ethics. Therefore, she argues that scientific research should be monitored by ethics committees made up of "specialists of a high scientific and moral standing", in order to stop certain experiments from being carried out such as human cloning for reproductive purposes. She does, however, agree with and accept the production of specific organs, like "a liver or a heart", from human embryos, for transplants.

> *"(...) we know that all scientists should be honest in their work, but some of them aren't. What a scientist investigating the cutting-edge wants is for his work to advance, he's not bothered much with ethical problems. (...) I think some of these studies should be authorised, because they'll have an important impact on humankind.* [Scientists] *should be monitored to see what's at stake. For instance, they shouldn't do human clones: I'm totally against that! (...) But certain things, such as taking an embryo and being able to make a liver or a heart to give some poor soul on his deathbed, I perfectly agree with! So, I think they should be monitored by someone who understands what's at stake and has a strong ethical stance."*
>
> *"In cutting-edge research you can't let each person do whatever he wants, there should be some control because you never know what they might do.* [That control should be exercised by specialists] *who have already reached a certain degree of maturity to be able to evaluate what's at stake."* (TI1)

Besides acknowledging the need for intervention by committees of specialists to control scientific and technological activity, Cristina is also in favour of citizens' active participation in this process. Consequently, one of her priorities as a teacher (accordingly to her own words) is to prepare her students for an active role in decision-making processes related to science and technology (TI1).

Conceptions about Teaching Biology and Geology

Cristina defends that Biology education in general, and the "Biology and Geology" subject in particular, are extremely important to the future of society. She believes that the survival of the human species and the solution of countless environmental problems depend on a science education that promotes the construction of basic scientific knowledge and the development of students' intellectual abilities.

She considers that all citizens should have at least some scientific knowledge regarding (1) the importance of the biological functions, and (2) the role each living being (humans included) has in maintaining life on Earth, as she feels that only through this knowledge will we understand the problems that emerge and decide in an informed manner: "Everyone has the right to scientific knowledge (...) so as to be able to justify their own choices, both in personal terms and in terms of the community." (TI1) As such, she stresses the importance of formal science education but also of scientific information made public through the media:

> "[This scientific knowledge is obtained] *by studying, of course, that's the first thing; furthermore, if there was more information in the media, then citizens would have access to the minimum scientific knowledge required to understand and make choices. For instance, when there are elections you'd know who to vote. I'm talking about things like a minimum group of ecological concepts."* (TI1)

Cristina also believes that citizens' participation in decision-making processes in regard to science and technology also depends on understanding the nature of these enterprises and their interactions with society. To reach this goal, she usually engages her students in activities involving analysis of current socio-scientific issues, discussion and decision-making. In her classes, students have to analyse and discuss real and imaginary cases related with: environmental problems affecting populations; genetic diseases, tests and treatments affecting families; new technologies affecting living beings. In all these situations, students are invited to decide and to justify courses of action based on scientific knowledge and also on their experiences and values. The different options are discussed in the classroom as a way to promote students' knowledge about science concepts and processes and also students' moral development. Through these discussions, students have the opportunity to confront opinions, to know each other better and to share knowledge and experiences in a climate of open discourse, respect and tolerance. In these classes Cristina pays special attention to the mutual influences between science and society, stimulating discussions about the impact of science on society and also the ways citizens can participate in (and influence) decision-making processes about scientific and technological options. One of her main aims is to empower students with competences necessary to actively participate in public discussions and decision-making processes (TI2).

In her classes in general she gives the students practical activities, worksheets and encourages debates or discussions about current issues, "as a way of stimulating their intellectual activity and facilitating their understanding of the concepts involved" (TI1).

Conceptions about the Discussion of Controversial Socio-Scientific Issues in the Classroom

According to Cristina, the "Biology and Geology" curriculum includes only a few controversial topics. However, she defends that the curriculum is not simply a list of topics and it is the teacher's job to work around it so as to include themes that are related to the planned programme units and which may interest the students and be socially relevant. She declares that throughout the school year she always addresses several controversial issues that she considers to be up-to-date and indispensable for students' scientific literacy, while at the same time "completing the programme". As such, Cristina adopts the role of curriculum builder (Roldão, 1999), changing it constantly according to her students' specific interests and competencies and the learning experiences considered to be socially relevant. But, in line with some studies (Levinson and Turner, 2001), she finds that some science teachers are reluctant to address controversial issues, for fear that discussion of these themes might not be welcomed by parents.

> *"A teacher can introduce controversy, if he/she wants. When it comes to reproduction (...), birth control and sexually transmitted diseases aren't part of the programme but I always address them as a complement to the programme. And within birth control: abortion, the use of embryos for research… It's a question of working around the programme. But there are people who are afraid to address these issues.*
>
> *In the 11th grade, I usually devote some of my classes to these topics because I think it's really important to do so. Students rarely know as much as they think they do."* (TI1)

Cristina does not regard the discussion of these topics a waste of time. On the contrary, she believes that discussing controversial socio-scientific issues is very important, both to gain knowledge about current scientific and technological issues that are relevant for life, and to develop skills in terms of analysing and discussing information that is essential to everyone. Therefore, she proposes carrying out discussion activities on themes such as cloning, birth control, *in vitro* fertilisation and sexually transmitted diseases. Through role-play, case studies and decision-making activities she triggers discussion about students' different opinions, experiences and knowledge related with controversial socio-scientific issues. With these activities she expects to develop the knowledge and the competences that, in her opinion, students need to cope with public discussions and decision-making processes. Once again, her opinion about the potential of discussing controversial issues as a classroom strategy shows her deep concern in promoting the understanding of knowledge and the development of intellectual competencies that she considers vital for her students' scientific literacy.

Like certain authors (Osborne and Young, 1998; Solomon and Thomas, 1999), the teacher claims that addressing these issues facilitates the establishment of relationships between the science taught in school and citizens' everyday experiences. She therefore constantly strives to identify contact points between the curriculum of the subjects she teaches and the current socio-scientific issues that are most related to the students' interests and daily lives.

Classroom Practice

This study involved the observation of a 14-class sequence planned and implemented by Cristina. This set of 50 minutes classes focused on programme topics (asexual and sexual reproduction, cell cycle, mitosis and meiosis) which, in her opinion (TI1), enable the introduction of controversial issues, such as cloning or genetic engineering. The observation took place in a single 11th grade "Biology and Geology" group taught by the teacher: the class consists of 19 students, with whom Cristina has a "very good relationship". After the observation of the complete set of classes, the teacher was interviewed about the goals, results reached, difficulties and successes of its implementation. This section presents some information obtained through classroom activities observation and posterior discussion.

For the sequence of classes that was to be observed, Cristina planned a set of activities she felt helped attain a double goal: (1) learning basic concepts of genetics (mitosis and meiosis), which is essential to understand the reproductive and hereditary process; and (2) the "preparation of the students for life" and "for making decisions as citizens", by teaching analysis and discussion skills of current and socially relevant themes.

> *"I would like to educate students not only so they have knowledge in Biology, which is essential nowadays and for their lives also in general, but also so they become useful members of society."* (TI3)

To fulfil these goals, and with the resources available, she proposed a varied set of classroom activities: observing structures and phenomena with lab instruments, group discussions, doing worksheets and viewing multimedia programmes (classroom observations – table 1). She believes each of these activities focus on specific objectives and corresponds to the students' different methods of learning. She believes that learning the rather abstract concepts in question is made easier by observing the structures and phenomena involved, and therefore resorted to textbook photographs and favoured observation of: a) different types of reproduction in species of plants using binocular magnifying glasses; b) cells at different stages in the cell cycle using microscopes; and c) animations of the mitotic process shown in a multimedia presentation. The importance of the phenomena under study was illustrated through examples related to current scientific and technological progress in the field of tissue culture, genetic engineering, gene therapy and cloning.

Table 1
Main activities observed during classes

Class (periods of 50 min)	Main activities and % of classroom time spent on each one
1	• Teacher asking students and discussing their ideas about concepts (13%); • Teacher presenting and discussing concepts through the exploration of images/examples and the establishment of connections with previous topics (24%); • Teacher establishing connections between concepts and real life situations/examples (10%); • Students observing different types of reproduction (in plants, fungus and microbes) with microscope and magnifying glasses (39%); • Teacher recapitulating the main concepts discussed (7%).
2	• Students' recapitulation of the main topics discussed in the previous class (6%); • Students (in pairs) answering questions from textbook (27%); • Students presenting and discussing answers to questions (15%); • Teacher presenting and discussing concepts through the exploration of images/examples (23%); • Teacher establishing connections between concepts and real life situations/examples (8%); • Teacher recapitulating the main concepts discussed (8%).
3	• Students (in pairs) answering questions from textbook (33%); • Students presenting and discussing answers to questions (19%); • Teacher presenting and discussing concepts through the exploration of images/examples (31%); • Teacher recapitulating the main concepts discussed (6%).
4	• Students observing different cells' cycle with microscope (71%); • Students presenting the main aspects of their observations (24%).
5	• Teacher and students discussing a multimedia presentation with animations and films of the mitotic process (76%); • Students recapitulating the main concepts discussed (13%).
6	• Teacher establishing guidelines for a discussion activity on advantages and disadvantages of plants' and animals' cloning (31%); • Students searching information about plants' and animals' cloning (using books, magazines, newspapers and Internet) (60%).
7	• Students selecting, organizing and discussing information about plants' and animals' cloning (Jigsaw methodology) (89%).
8	• Students discussing information about plants' and animals' cloning (Jigsaw methodology) (91%).
9	• Students' groups presenting conclusions to all class (48%); • Students discussing the presented conclusions about plants' and animals' cloning under teachers' supervision (43%); • Teacher recapitulating the main ideas discussed (5%).
10	• Teacher establishing guidelines for a discussion activity about the implications (biological, social, ethical, etc.) of human cloning (15%); • Students (in groups of four) writing a story about the life of a cloned human being (all groups starting from the same initial plot) (81%).
11	• Students' groups presenting the story to all class (71%); • Students discussing the different story plots under teachers' supervision (21%).
12	• Teacher presenting and discussing concepts (meiosis and sexual reproduction) through the exploration of images and the establishment of connections with previous topics (36%); • Teacher establishing connections between concepts and real life situations/examples

	(11%); • Students observing different phases of meiosis with microscope (35%); • Teacher recapitulating the main concepts discussed (11%).
13	• Teacher presenting and discussing concepts through the exploration of images/examples (45%); • Teacher establishing connections between concepts and real life situations/examples (13%); • Students (in pairs) answering questions from textbook (29%).
14	• Students (in pairs) answering questions from textbook (35%); • Students presenting and discussing answers to questions (47%).

In all the classes observed, Cristina was clearly concerned with diversifying strategies and showing the importance of the topics she approached, by establishing relations between these topics and certain current scientific and technological progress. The activities carried out required the students' active involvement in observing structures or phenomena, in researching information, in analysing and discussing socio-scientific issues, in solving questionnaires and in presenting work. Another important aspect of her classes was the kind of oral interaction that was established, precisely because it was not confined to a teacher-dominated question-answer sequence. In several classes, particularly in those that involved discussion, the students dominated the discourse and Cristina remained in a role of tutor. After introducing the topic and presenting the task, she restrained herself from exposing her own opinions, acting as a chairperson with the aims of ensuring quality and fairness in the discussion and helping students to a deeper level of understanding. In the discussions she didn't force students to reach a consensus, protecting divergence of view among them. Her aim was to help students understand and explore the implications of different opinions and actions (TI3).

Aimed at "preparing students for life" and promoting reflection about science, technology and their interrelations with society, Cristina turned to two discussion activities about a controversial issue, linked to the concepts at stake: cloning. In the first activity she intended each group of students to reflect and formulate a critical opinion about eventual advantages and disadvantages of plants' and animals' cloning. To do so she suggested the analysis and discussion of articles published in books, newspapers, magazines and the Internet. This activity was organized accordingly to Jig-saw methodology (Aronson, 1978). At the end, the conclusions of different groups were presented and discussed by all class. The second activity was aimed at thinking about the implications (biological, social, ethical, etc.) of human cloning. Starting from the same initial plot, each group of students made up a story about the life of a cloned human being. Cristina is adamant that these activities will engage the students and help them (1) to build up knowledge that is relevant for the future and (2) develop the ability to think and argue, which is indispensable for taking part in decision-making processes:

> *"In relation to these activities about cloning, this is a contemporary problem and it gives them an idea of the importance of the phenomena that we are studying, allowing them to make decisions as citizens, which I believe is vital. (…) The most important thing is for them to have a range of material from which they can*

> *choose and create an opinion… Because not everything that's in the newspapers is true...*
>
> *(...) It is also important that they prepare themselves to take part in debates. (...) So the subject is important in itself, but so is another thing: the ability to work as a team on a particular subject to obtain data with which they can later argue (...) and base their ideas on. I think this is very important. I think this is a life lesson, not just a lesson in Biology."* (TI3)

The teacher's enthusiasm throughout the observed activities was clear and transmitted to the students. The classroom atmosphere, warm and welcoming as well as intellectually stimulating, helped the rapport between students and teacher. The classes on cloning were particularly spirited, with many subjects being discussed: a) types of cloning; b) the possible applications of cloning of plants and animals; c) the possibility of cloning killers and dictators; d) the relative weight of heredity and the environment in defining the physiognomy and personality of individuals; e) the ethical implications of human cloning; f) the activity of scientists; and g) the role of the scientific community, government and citizens in controlling research. In these classes, Cristina's motivation was particularly high, having taken an active part in the discussions, asking for explanations, presenting information, summarising points of view and moderating student participation.

From these observations, it can be said that Cristina's teaching practice takes into account several elements of what contemporary literature defines as a good environment for learning. According to Simons, van der Linden and Duffy (2000), the long-lasting, flexible, functional, significant, generalised and applicable competencies that are demanded in contemporary society require a type of learning that is research-oriented. This learning should be also focused on real-life problems and cases, involve interaction between many people, and with an implicit motivation capable of arousing interest in students. From the authors' viewpoint, it is only through a more active, hands-on learning process that we meet these new demands.

At the end of these monitored classes, Cristina was visibly happy with the quality of output and interactions, the level of understanding of the subject matter, and the clear "development of a critical attitude towards news items" regarding scientific and technological issues, the level of consideration about the construction and evolution of scientific knowledge, as well as the students' level of satisfaction (TI3). However, she believes she can always do better and next time she would like to show another film illustrating the dynamics of mitosis and meiosis.

Cristina's classes were clearly influenced by her ideas on the nature, the teaching and the learning of science. Bearing out the results obtained by Lederman (1999), the consistency between the teacher's conceptions and her classroom practice seems to have been strongly influenced by the teaching aims she set for herself. Another factor that is in keeping with this aspect was the type of pre- (internship) and in-service education (Calouste Gulbenkian Foundation courses), that allowed her to "learn by doing" (TI1) under the supervision of more experienced colleagues and developed the taste and the confidence to keep trying new approaches, methodologies and strategies in her teaching. As Stofflett and Stoddart (1994) pointed out, teachers who experience active approaches to teaching have a greater tendency to use this kind of approach with their students.

Her ideas about scientific activity, namely about its relations with technology and society and about the provisional, dynamic character of scientific knowledge, are reflected in the strategies she suggested about the controversy regarding cloning and in the way she conducted the discussion of this topic. Unlike other cases described in research (Brickhouse, 1990; Duschl and Wright, 1989; Lederman and Zeidler, 1987), the length of the curriculum and the pressure to cover its contents did not stop Cristina from discussing controversial socio-scientific issues and addressing aspects of the nature of science. Several factors seem to have contributed to this fact: a) the importance she attributes to teaching controversial issues and aspects of the nature of science; b) her intention to explicitly address these topics; c) the level of knowledge about controversial socio-scientific issues and the strategies required to teach these issues; and d) the way she develops the curriculum, adapting it to the needs of each class, in particular, and of society, in general.

In Cristina's case, the impact of her conceptions about science teaching on her practice was clearly felt, namely: a) in the diversification of strategies; b) in the creation and implementation of activities requiring students' active involvement; c) in implementing a teaching method focused on the development of skills and on the construction of relevant knowledge for life; and d) in resorting to current, relevant topics as a starting point for research and discussion activities about the potential and constraints of scientific and technological knowledge.

Final Remarks

Cristina reveals a positive image of science and technology, chiefly because of the role of these fields of knowledge as catalysts for progress and social development. However, the controversy surrounding several current socio-scientific issues fortifies her fears concerning the improper use of science and technology, motivated by the values and interests of specific individuals or groups. Subsequently, in her classes, Cristina strives to develop the knowledge and skills she feels are essential for her students to enable them to understand and evaluate scientific and technological enterprises.

Based on the current controversies regarding scientific and technological issues, Cristina explicitly rejects the myth of objectivity and neutrality of science, admitting the influence of personal, social, institutional, environmental, cultural, ethical, economic and political factors in scientists' activity (an influence that is clear in socio-scientific issues). The teacher considers that these controversies, which the media talk about so often, stem from the diversity of values and interests of society at large and of the scientific community in particular.

Cristina's conceptions about science influence her classroom practice, presenting scientific activity as a complex, dynamic human enterprise that involves value issues and is therefore controversial. She believes that socio-scientific issues are not limited to technical discussions; rather, they involve other aspects (value hierarchies, personal conveniences, financial matters, social pressures and so on) that lead to differing opinions among experts. Consequently, she recognises the importance of involving citizens in the evaluation of the potentialities and limitations of scientific and technological progress and thus seeks to prepare her students for this task. To do so she often resorts to current socio-scientific issues as the starting point for research and discussion activities about the potential and restraints of scientific and technological knowledge. While also addressing the full programme contents, the teacher focuses her practice on the development of relevant skills and knowledge for life.

This case reveals a conception of curriculum as a creator of competencies that stresses the possibility for teachers to manage content and choose the educational experiences according to students' specific characteristics and the unique contexts in which they work. In line with the latter, the teacher assumes the role of curriculum constructor (and not just consumer/executor) and is more concerned with how to develop specific competencies that she considers relevant than with the lengthy curricular contents themselves.

Cristina's classroom practice is influenced by her conceptions about teaching and curriculum and, and by the educational goals she sets for herself. Classroom practice is influenced by: a) an understanding of the curriculum allowing for levels of decision-making suited to the needs of society and of the specific context; and b) a conception of science education focused both on knowledge construction and on the development of skills and attitudes (required for citizens' intellectual autonomy and for exercising their citizenship) by actively engaging students in a varied range of activities.

Her conceptions about teaching and curriculum were strongly influence by the internship and the summer courses organized by Calouste Gulbenkian Foundation she attended early in her career. These situations provided the opportunity to experience, implement and evaluate completely new approaches under the supervision of science education experts.

Cristina's strong personal beliefs (regarding the importance of promoting the discussion of controversial socio-scientific issues and explicitly addressing aspects of the nature of science), together with her in-depth knowledge of the subject matter and the knowledge she has concerning her students, the aims of science education and the strategies to carry it out, allow her to overcome any obstacles to the implementation of discussion activities about controversial socio-scientific issues. Her beliefs and professional knowledge grant her a remarkable capacity to interpret the curriculum so as to address the topics and carry out the activities she considers important and relevant.

This particular case shows that the implementation of the discussion activities about controversial socio-scientific issues depends decisively on the teacher's convictions about the educational relevance of these activities and the knowledge needed for their design, management and assessment. The development of these convictions and competences can be triggered by professional development opportunities in which the teacher experiences new approaches under experts' supervision. The involvement of teachers in experiencing and discussing the educational potential for the discussion of socio-scientific issues can be a positive step forward in changing their teaching styles, especially as regards the diversification of teaching strategies and the development of the didactic knowledge required for their use in the classroom. This is a promising path that we are exploring in the implementation of professional development initiatives aimed at supporting teachers in planning and carrying out both discussion and experimental work.

Appendix 1 – Script of interview TI2

1. What are the general objectives/aims of the unit?
2. Describe the activities planned for the unit.
3. What are the objectives of each of the planned activities?
4. What reasons led you to choose these activities instead of others?
5. What difficulties are you expecting to find? Do you expect your students to experience some difficulty? Explain your answer.

Appendix 2 – Script of interview TI3

1. Are you happy with the way your classes ran? How do you evaluate your classes?
2. Did they go according to plan? Were objectives met?
3. Was students' behaviour/reaction suitable?
    a. If NOT: When? Why? What are the causes?
    b. If SO: Describe their behaviour. Why do you say it was suitable?
4. Next time you address these issues will you do anything different? Why?
    a. With what finality/objectives did you carry out the activity…?

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