Influence of views about the nature of science in decision-making about socio-scientific and pseudo-scientific issues

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Abstract

The purpose of this study was determine which ideas about the nature of science (NOS) were used by students to make decisions regarding a variety of contexts. 128 undergraduates, enrolled in a Science and Society course, were asked to decide what action they would take—both at the start and the end of the course— in a situation about pseudoscientific, socioscientific issues (SSI), and non-controversial scientific issues, about which students had differing degrees of familiarity. At the same time, students' views of the NOS were also assessed. Generally speaking, students' views were naïve and—together with their decision-making processes—did not improve after the course. In all cases, familiarity with and prior knowledge of the issue influenced how students justified their decisions. In pseudoscientific scenarios, when the issue (quantum medicine) was mostly unknown to students, many students appeared to be more open to pseudoscientific ideas and to distrust scientists, in contrast with more familiar issues (Aids and weight-loss pills). All students who used ideas of the NOS (endorsement/rejection by the research, appeal to the authority of scientists, caution due to the lack of evidence) to justify their decisions in these kinds of scenarios rejected pseudoscientific arguments. In the case of SSI scenarios, many students used ideas of the NOS (caution due to the lack of evidence) to make their decision, even though personal experience (mobile phones) and risk/benefit analysis (genetic modification for the purposes of curing disease) also played a preponderant role. In non-controversial scientific issues (smoking, diet and self-medication) students barely used ideas of the NOS: personal tastes and preferences were the most widely used criterion. These results contrast with previous research in which ideas of the NOS were not found to play an important role in decision-making. They also suggest that ideas about the NOS are useful for the decision-making process and depend to some extent on the context.

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Chapter 1. Introduction

Currently, there is considerable emphasis in science education on the training of scientifically literate individuals. The meaning of 'scientific literacy' has changed with time and the particular interests of whoever has advocated it in the past. However, many in the research community agree that scientific literacy must, among other things, develop critical thinking skills in people that allow them to draw conclusions from the available evidence. Additionally, scientific literacy must equip people with the necessary skills to search, understand, and evaluate information about science-related topics, information that, in its turn, should enrich their decisions about everyday scientific issues (for example, see Collins, 1998; Millar and Osborne, 1998; OECD, 2003; Zeidler et al., 2003)

It has been advanced that a developed understanding of the nature of science (NOS) can contribute to the achievement of these objectives (Kolstø, 2001; Walker & Zeidler, 2007). It has also been suggested that an adequate view of how science works would allow students to differentiate science from pseudoscience (Bell & Lederman, 2003). This skill is important in a society where a great deal of products and services based on pseudoscientific principles are on offer, products that can harm people's health and endanger their lives, to say nothing of the damage to their economic situation. However, up until now whether or not views of the NOS can play a positive role in decision-making regarding scientific issues, helping to distinguish science from pseudoscience, remains controversial.

Studies conducted thus far have researched the use of ideas of the NOS when individuals make decisions about socioscientific issues (SSI). These SSI are complex, do not have a correct answer, and require—for their resolution—not only knowledge of and about science, but ethical, social, political, and economic considerations. One of the main limitations of existing studies lies in their use of a reduced number of situations about which participants have to make a decision.

The fact that, in general, research about the use of the NOS has not emphatically explored the influence on decision-making of the particular situation or context faced by individuals, and under which the decision takes place, is quite intriguing. On the one hand, it is known that individuals find it difficult to transfer their ideas of the NOS to new situations (Abd-El-Khalick, 2001), on the other, it has been shown that the degree of familiarity with a given situation and the beliefs involved affect the way people assess situations (Zeidler, 1997).

Another limitation of these studies is that they have, for the most part, focused on SSI. These are quite important issues that involve controversial matters about which people have to make a decision with the potential to affect their everyday life. However, other issues have been pushed into the background in these studies. Among these issues are pseudoscientific ones and decisions related to matters where there is no scientific controversy involved. At first glance, it can appear to be the case that pseudoscientific issues have no place in science classrooms. However, the ability to distinguish pseudoscientific claims can directly affect people's lives and decisions, particularly with respect to health. If science education intends to fulfil the aims advocated by scientific literacy initiatives, it should strive to equip people with the necessary tools to make informed decisions about these kinds of topics. Additionally, on a daily basis people find themselves in situations where they have to make a decision about uncontroversial issues with a scientific component, such as diet, exercise, and smoking.

This study strives to fill the gap left open by prior research on these matters and explore which kinds of ideas of the NOS students use in a variety of contexts—pseudoscientific, SSI, and well-established science.

On the other hand, as a result of current trends that incorporate views of the NOS into science education, educational authorities in Mexico have added these topics to the new science curriculum for secondary school and some scientific and technological degrees. This study took place in University A, a Mexican public university where, recently, a course intended to develop analytical skills and an understanding of the links between science and society in students was included in the syllabus. One of the aims of the course is

> that students develop a better understanding, attitude, and sensitivity to cultural aspects of science, either of a philosophical, social, historical, ethical, or political bent, and the interrelationship among Science-Technology-Society, with an emphasis on the study of chemistry, with the ultimate aim that students develop into citizens capable of making informed and reasoned decisions in a democratic society, guided by experimentation, communication, critical thinking, and intellectual independence.
>
> (Syllabus from University A, Mexico, 2006)

Given that this course emphasises the understanding of scientific activity (specifically of the NOS) with the aim of training individuals capable of making informed decisions, it represented a suitable opportunity to assess the effect of views of the NOS in decision-making in a variety of contexts.

The following research questions were formulated for this research project:

- What ideas about the NOS do students draw upon when asked to make a decision on a socio-scientific issue, a well-established scientific issue or pseudo-scientific issue?
- What differences exist in the ideas about the NOS that students draw upon when making a decision on controversial socio-scientific issues, well-established scientific issues or pseudo-scientific issues?
- To what extent are students' ideas about the NOS associated with the acceptance or rejection of the option presented?
- To what extent do students' ideas about the NOS change after taking a course focused on the relationships between science and society?
- To what extent do ideas about the NOS that students draw upon when making decisions on socio-scientific issues, well-established scientific issues, and pseudo-scientific issues change at the end of the course?

The more relevant ideas from the research literature that influenced the design and analysis of this study are presented in Chapter 2. This chapter analyses the ways in which the balance within the conceptualisation of scientific literacy has shifted from an emphasis on scientific concepts to an emphasis on skills and knowledge that allow individuals to face everyday situations where science is involved. Afterwards, the text presents the ideas of the NOS—and students' commonly held misconceptions about them—that have been advocated for the purposes of science education. Some of the efforts that have been made to change students' and teachers' views of the NOS, what their focus, successes, and limitations have been are also explored.

The use of socioscientific issues as teaching tools is discussed subsequently. This topic is explored further by reviewing studies dealing with the strategies used by students when faced with an SSI. Finally, there is a brief section that covers the scant literature published on the influence of scientific knowledge or views of the NOS in people's disposition to believe in pseudoscience.

Chapter 3 presents, first, the rationale of the study, together with the context under which it was carried out. Afterwards, the methods used to determine and analyse students' views of the NOS and assess their decision-making processes are described. This chapter ends with a description of the sample used in the study and of the data collection.

The results obtained in the questionnaire that assess views of the NOS are presented in Chapter 4. This chapter focuses on the views of students regarding observations and inferences, the tentativeness of science, the relationship between scientific theories and laws, the social and cultural embeddedness, the role of creativity in science and scientific methods. The impact the course had on the assessed views is also described and analysed.

Chapter 5 presents the results of the decision-making questionnaire, both before and after the course. It begins with a description of the categories drawn from students' justifications. The rest of the chapter is divided in three sections: pseudoscience, SSI, and well-established science scenarios. Each of these sections has a similar structure. They describe and analyse students' decisions, justifications, possible relationship between the results of the decision and its justification, and responses to additional questions posed by the questionnaires. A final section presents the results of a cluster analysis whose purpose was to explore the consistency of students' responses to the different scenarios.

In Chapter 6, the findings presented in Chapters 4 and 5 are discussed in the light of the research questions and compared with the relevant literature. First it presents the results of students' views about the NOS, itemised by topic, and then afterwards their responses to the decision-making questionnaires. This section is also structured according to the type of context, in order to appreciate its influence.

In the last chapter of this thesis, Chapter 7, the conclusions drawn are presented. A consideration of the strengths and limitations of the study is also made. The chapter continues with suggestions for the project's implications for research in the area, curriculum development, teaching practices, and professional development of teachers are described. Finally, the chapter concludes with ideas for future lines of research drawn from the results of this study.

Chapter 2. Literature Review

At the heart of this research project lies the assumption that one of the purposes of science education is to produce scientifically literate citizens able to deal with science-related situations that might arise in their everyday lives. Therefore, a section of this chapter is devoted to discuss the relevant literature on scientific literacy: the development of the concept, and its different meanings and approaches.

According to many science educators, scientifically literate individuals must understand how science works, that is, have sophisticated ideas about the nature of science (NOS). The next sections of the literature review explore what are the ideas of the NOS that science educators have proposed should be part of science curricula. They also give an account of students' misconceptions about the NOS and the efforts made by different research groups in order to improve such views.

In spite of the supposed usefulness of these ideas for people, the role that they actually play in everyday life and decision-making remains controversial. This is why the literature review continues with an account of the ways individuals make decisions about socioscientific issues, and whether ideas about the NOS influence these decisions.

Besides facing socioscientific issues, people encounter in their everyday life other kinds of situations that necessitate knowledge of and about science for their resolution. Such is the case of pseudoscientific claims. Individuals should be able to differentiate these pseudoscientific ideas in order to make decisions that may even affect their health. The last section of the literature will then focus on pseudoscience and the role that scientific knowledge and ideas of the NOS play in the acceptance or rejection of such claims.

2.1. Science Education and Scientific Literacy

Today, when science and technology play such an integral role in everyday life, it has become commonplace to accord science—and technology—education an important place in both formal and informal education. Thus, as one of its chief aims education strives to equip people with knowledge necessary and sufficient to lead fulfilling and responsible lives (1989; Laugksch, 2000).

Throughout its history, science education has been the subject of much debate and innovation. The following review will provide a brief account of how science education has changed since it was first introduced in the late nineteenth century; when and how the concept of 'scientific literacy'—with its many definitions and objectives—emerged; and how perspectives on science education have changed in the light of the changing roles individuals are expected to play in society, democratic or otherwise. The content of this review will cover the context in which the notion of 'scientific literacy' appeared, as well as the social needs it was intended to meet. Subsequently, an account of what constitutes scientific literacy will seek to offer a broad perspective of the various ideas science educators and curriculum designers have held in the past about what it is to be scientifically literate. Finally, as a conclusion to these two sections, the objectives ascribed to science education are laid out so as to ponder the question: What is the role of science in the education of citizens capable of making responsible decisions?

2.1.1. A historical perspective

From the moment science education was first introduced in schools, a number of trends, goals, and approaches have characterised its application in classrooms. These have changed continually according to prevailing social and historical circumstances.

In 1605, the philosopher Francis Bacon was the first to suggest that teaching science had to be useful in some way (Solomon, 1994). However, it was not until the nineteenth century when science education was finally introduced in schools throughout the United Kingdom and the United States. Besides imparting some factual knowledge about the natural world, one of the expected outcomes of science teaching was that students used the inductive method, based on drawing conclusions out of the empirical observation of the world. As early as 1898, the application, across different contexts, of what had been learnt was also included as an important educational outcome (DeBoer, 2000):

> The main object of education, nowadays, is to give the pupil the power of doing himself an endless variety of things which, uneducated, he could not do. An education which does not produce in the pupil the power of applying theory, or putting acquisitions into practice, and of personally using for productive ends his disciplined faculties, is an education which missed its main aim (Eliot, 1898, pp. 323-324; cited in DeBoer, 2000).

This conception of science education emphasised teaching and learning concepts that, conceivably, could be put to later use in unspecified ways. Nevertheless, it did not conceptualise science teaching as a means of enabling citizens to deal with everyday situations or participate in decisions that concern part, or the whole, of society.

At the beginning of the twentieth century, educators asked themselves what could science contribute to the common citizen (Solomon, 1994). In the first half of the twentieth century, the philosopher and educator John Dewey promoted science education arguing that it enables citizens to act independently and to perform their duties adequately within society (Miller, 1983; DeBoer, 2000). Dewey's ideas proved influential: at the time, several educational policies were inspired by the conviction that school science should have a positive impact on people's daily lives (DeBoer, 2000). Nevertheless, Dewey's ideas about science education as the means to produce better citizens were never tested systematically. Neither were they included consistently in science curricula (Shamos, 1995).

Complications ensued not long after the start of science teaching. For example, achieving the right balance between the depth with which scientific concepts were taught and the relevance they should have for students' daily lives (i.e., one that should foster active participation in society) proved difficult. Consequently, at different times in the history of science teaching this balance has shifted from one outcome to the other (DeBoer, 2000). Depth and relevance represent two alternative ways of conceptualising science education: the first emphasises concepts; the latter, citizenship and the contexts within which science is taught, learned, and applied. At certain points in history, an effort has been made to make them more compatible with each other, with more or less success. On other occasions, one has been privileged over the other. Adopting depth or relevance as educational outcomes depends on factors such as culture, national and political ideologies, economics, and the idea of progress, among others.

After the Second World War, the American report *The Cardinal Principles of Secondary Education* outlined the principles that ought to guide education in general, and science education in particular. These principles advocated an education both civic and ethical—a notable departure from teaching abstract concepts in science classes (Bybee, 1997).

In the late fifties, Paul DeHart Hurd coined the term ‘scientific literacy’ for the first time to advocate the new, post-war goals of science education (Bybee, 1997). In that same year, a report on the state of science teaching commissioned by the Rockefeller Brothers Fund also made passing reference to the term (DeBoer, 2000). Importantly, Hurd reintroduced the idea that science education ought to have an impact on students’ daily life as well as prepare them to fulfil the role of responsible citizens.

In this period, science and technology went hand in hand, and the notion of scientific literacy addressed the pressing need to increase awareness of the positive and negative effects science and technology could have on society—effects made painfully clear in the aftermath of the Second World War (Aikenhead, 1994; Shamos, 1995; Laugksch, 2000). The consequences of the Second World War were not, however, the only influence on science education: the harmful effects on the environment of some industrial products and processes, such as pesticides (DDT), had already begun to dawn on people. Industrialists and scientists were not required by law to make publicly available data on the full range of effects of their products. Quite apart from accountable reports, citizens needed the means to understand and interpret what information was available (Solomon, 1994). At the time, the focus of science education was placed squarely on teaching functional knowledge (Bybee, 1997).

Against specialisation for specialisation's sake, the so-called 'scientific literacy movement' inaugurated by Hurd was intended for a general public. Its main goal was to promote the proper use of science and technology, as well as educate people about the risks and consequences of their misuse (Shamos, 1995). The movement thus aimed to prepare critically-minded individuals capable of understanding the role of science in society (DeBoer, 2000).

One of the main strategies employed to achieve the goals of scientific literacy was the introduction of socio-scientific issues into formal education curricula. Its proponents assumed that, through them, a 'science for effective citizenship' would be achieved and students would be able to deal intelligently with scientific issues that actually affect society (Shamos, 1995, p. 82). However, socio-scientific issues were underused as teaching tools: scientific knowledge was mostly used in an isolated manner—without taking into account that science is part of society and carries with it moral implications—to attempt to solve problems, particularly from the developing world. Science was portrayed as a triumphalist enterprise associated with progress (Solomon, 1994).

Apart from the not so subtle ideological charge behind the image of science as progress, science subjects were included in curricula with the overt aim of indoctrinating students and producing compliant citizens: people who know what the scientific enterprise is about are more likely to lend support to it, or so it was argued (DeBoer, 2000). This notion has now been questioned by some science educators (see Millar, 1996).

During the Cold War period, the space race had a great impact on the United States' science curricula. The Russians were ahead after having successfully launched Sputnik in 1957 (Shamos, 1995; Laugksch, 2000). Under these circumstances, one of the main concerns in the United States—during the late fifties and the early sixties—was training scientists and technologists capable of contributing to global scientific and technological supremacy. There was also interest in achieving an education that prepared students to face the rapid development of science and technology while, at the same time, inclined the general public to lend support to the scientific enterprise—a reprise of the instructional and ideological drives of the scientific literacy initiative.

In order to achieve scientific and technological supremacy, during the sixties most curricula were given to scientists to design, who in turn emphasised the teaching of scientific concepts and models, neglecting the relationships between science and society and the role of education as an agent for citizenship. Curriculum designers believed that the emphasis on scientific knowledge would lead to military and economic growth. Courses ended up being very detailed—content-wise—and difficult for most students (DeBoer, 2000). The immediate result of such a reorientation of the curriculum was a decrease both in admissions to science degrees and in the number of high school students opting for science subjects (Bybee, 1997).

Over time, many science educators took issue with the overemphasis on scientific concepts and models. Several factors triggered a refocus of educational aims in the 1970s: students had lost interest in science both as a subject and, consequently, as a career choice; there was widespread recognition that science was immersed in society; 'education for all' became a desirable, and much sought after, outcome; technology was incorporated into science education (Aikenhead, 1994). At this juncture, the term 'scientific literacy' was introduced again to describe, and guide, the teaching and learning of science and broaden its meaning and implications, namely, by pointing out its applications in everyday life and its relationship to society. Among the aims of education during the 1970s was easing the transition into adulthood and fostering participation in the community. Several reports were published in that decade detailing environmental problems that, together with protests against the war on Vietnam, brought about greater participation in civil issues (Bybee, 1997).

According to the National Science Teachers Association (NSTA) in the United States, a scientifically literate person 'uses science concepts, process skills, and values in making everyday decisions as he interacts with other people and with his environment' and 'understands the interrelationships between science, technology and other facets of society, including social and economic development' (National Science Teachers Association, 1971, pp. 47-48; cited in DeBoer, 2000, p. 588). This change of direction, with respect to previous ideas of scientific literacy, recognised that a person needs much more than knowledge about scientific concepts and models in order to be able to participate in society responsibly—it acknowledges that, besides scientific skills and values, people need social ones in order to make decisions.

Thereafter, scientifically literate persons were defined as citizens who both knew how science works and were capable of using their knowledge to make everyday decisions. Science was supposed to empower citizens to become active agents in society. By broadening its scope, science education came to include, as an educational outcome, the application of scientific knowledge in different contexts. That was why the Science-Technology-Society (STS) movement was created within science education as an initiative to promote participation in society and the understanding of the relationships among science, technology, and society. This movement distinguished itself from traditional science teaching by not presenting science as a morally neutral enterprise, but rather inviting students to assess the moral dimension of science, as well as how socially just it was (Solomon, 1994).

In the nineties, the balance shifted yet again. Science educators in the United States perceived a crisis in science education, as evidenced by the poor performance of American students in international examinations. At this juncture in time science education was—like so many times in the past—considered fundamental for the economic growth of the country (Laugksch, 2000). Educators asked for more academic rigour and an increased emphasis on scientific concepts. In response, in 1989 the American Association for the Advancement of Science published *Project 2061. Science for All Americans*, a policy document detailing a comprehensive reform of the educational system to the satisfaction of the scientific community (DeBoer, 2000; Murcia, 2009).

This report argued for the need of scientifically literate citizens and listed a series of recommendations for achieving this goal. It emphasised teaching the relationships among science, mathematics, technology, and the social sciences, as well as of the knowledge of general scientific principles. This policy document is important because it attempted to operationalise and systematise the concept of ‘scientific literacy', as well as define its goals and the main ideas a scientifically literate person should possess (American Association for the Advancement of Science, 1989; Murcia, 2009). The reform advocated was an ambitious one—the syllabus proposed included a large number of scientific concepts, some aspects of the nature of science, and the relationship between science and society.

Fulfilment of all the goals established by this reform would have ensured that all students achieved an acceptable level of scientific literacy and those wishing to pursue a scientific career would have had enough basic knowledge to do so. This is one of the report's main contributions: it attempts to make compatible, in a systematic manner, the two main tendencies in science education—the one that emphasises scientific concepts and the one that emphasises applicability to students' everyday life and increasing social participation.

Changes in the meaning of scientific literacy, alternatively from an emphasis on scientific concepts to an emphasis on the usefulness of science for everyday life, has influenced the profile of students who graduate from basic instruction. In the first case, students are supposed to know the main scientific ideas and processes, whereas in the second, educational aims go well beyond content knowledge to encompass the instruction of citizens capable of using their knowledge of and about science in their daily life. This second objective has been difficult to achieve in practice. In what follows, it will be discussed how different aspects of science teaching influence decision-making in students.

2.1.2. What is scientific literacy?— Diverse trends

In the previous section, different approaches to science education were examined. Particular attention was paid to the shifts in the emphasis given to particular science content—from the highly technical and specialised to the applicable to everyday life—and the relationship between science and society, as well as to the importance of science teaching and learning to prepare responsible citizens. Along with these changing perspectives in science education, what scientific literacy was understood to be has changed as well, together with what it means to be scientifically literate and why societies need scientifically literate citizens.

Although the term scientific literacy is widely used today, even as a slogan (Bybee, 1997), there is no agreement on its exact meaning. It has been defined in several different ways, each one a reflection of its author's stance and the context of the time. In this section some of these definitions, their objectives, and approaches will be discussed. Also, the difficulties of operationaling it will also be addressed.

When the term scientific literacy was first advanced in the late fifties, it was not defined with precision. The term implied knowledge of scientific concepts, of how science works, and of the role of science in society (Bybee, 1997; DeBoer, 2000). For Hurd, scientific literacy should picture science as an intellectual achievement and provide people with a wider perspective from which to assess societal problems (Bybee, 1997). According to Durant (1993), broadly speaking, scientific literacy refers to 'what the general public ought to know about science' (p. 129). This definition, which at first sight might seem straightforward enough, has nevertheless been interpreted in several different ways—its meaning has even been compared with that of science education (Shamos, 1995; Laugksch, 2000).

As can be expected, then, there have been several attempts to clarify the concept of scientific literacy. One of the first efforts in this regard was due to Pella and co-workers (1966; cited in Laugksch, 2000). Pella et al. reviewed one hundred articles on science education published between 1946 and 1965 and then identified the features that most authors considered a scientifically literate person should possess. Among the features commonly mentioned were understanding the links between science and society, the ethics of scientific work, the nature of science, the differences between science and technology, some basic scientific concepts, and the relationship of science with other forms of knowledge, such as that of the social sciences (Laugksch, 2000; Murcia, 2009). It is noteworthy that already this early attempt to systematise the meaning of scientific literacy makes reference to knowledge about how science works. Its main focus is on knowledge individuals should have of and about science.

In 1970, Donald Daugs ascribed the failure of previous scientific literacy inititatives to the lack of a clear definition of their objectives (Bybee, 1997). In a later study, Showalter (1974; cited in Laugksch, 2000) reviewed the literature again and came up with seven dimensions, or aspects, that describe a scientifically literate individual:

> The scientifically literate person understands the nature of scientific knowledge.
>
> The scientifically literate person accurately applies appropriate science concepts, principles, laws, and theories in interacting with his universe.
>
> The scientifically literate person uses processes of science in solving problems, making decisions, and furthering his own understanding of the universe.
>
> The scientifically literate person interacts with the various aspects of his universe in a way that is consistent with the values that underlie science.
>
> The scientifically literate person understands and appreciates the joint enterprises of science and technology and the interrelationship of these with each and with other aspects of society.
>
> The scientifically literate person has developed a richer, more satisfying, more exciting view of the universe as a result of his science education and continues to extend his education throughout his life.
>
> The scientifically literate person has developed numerous manipulative skills associated with science and technology
> (Laugksch, 2000, pp. 76-77).

The difference between Pella's work and Showalter's lies in the latter's emphasis on knowledge, skills, attitudes, and values related to science. Besides, in Showalter's alternative proposal individuals must be able to interact with their surroundings in order to understand them and make informed decisions. However, this definition fails to prescribe that a scientifically literate individual must be able to participate actively in decision-making processes concerning scientific issues that affect society.

In contrast to the notion of a unique set of characteristics that define scientific literacy unequivocally, other authors have suggested that there is more than one type of scientific literacy, depending on its objectives, its intended public, and the degree of involvement required from citizens. For example, there is a so-called 'practical scientific literacy', which involves solving everyday situations using scientific knowledge; a 'civic scientific literacy', characterised by the public's awareness of socio-scientific issues and active engagement in informed decision-making; and a 'cultural scientific literacy' that promotes an understanding and appreciation of science as a human achievement (Shen, 1975; cited in Laugksch, 2000, p. 77).

Miller (1983) also categorised scientific literacy according to two dimensions: on the one hand, individuals must have knowledge of science and about science, as well as the ability to interpret it and express an informed opinion. However, Solomon (1994), in spite of agreeing with the desirability of these attributes in a scientifically literate populace, questions how feasible it is for individuals to develop their own viewpoints regarding scientific issues. Knowledge transfer between the school and a wider social context is itself a barrier. Solomon argues that crossing it implies more than just understanding scientific contexts related to an issue—it requires defining a posture about it.

Thomas and Durant (1987) believe that scientific literacy should help citizens to reap benefits from science and technology and avoid feelings of intimidation or oppression from them. This notion implies empowering citizens to allow them to engage with scientific and technological development.

The point of view expressed by Shamos (1995) regarding scientific literacy and decision-making is more radical still. He argues that a curriculum that promotes the development of students' scientific thinking is a waste of time and resources. He suggests that current curricula do not even promote scientific literacy, but rather the training of future scientists. It is unrealistic to expect the general public to reach on its own independent judgements or viewpoints regarding scientific issues related to society. Shamos—contrary to widespread opinion of what scientific literacy should enable people to do—suggests that, as a result as a curriculum that emphasises literacy, individuals should be favourably disposed to approach, and trust, scientific experts to guide their decisions about these kinds of issues. To achieve this, people should know how science works, that is, what is the nature of science.

Shamos also argues that there are three hierarchical kinds of scientific literacy, each more advanced and complex than its predecessor. The first one is called 'cultural scientific literacy', and it is the kind that most educated adults possess. This kind of literacy allows one to recognise scientific topics and terms in newscasts and other popular sources of information. The second kind is 'functional scientific literacy', which enables individuals to play a more active role, since they can read, write, and talk coherently about scientific topics at a basic level. The third kind of scientific literacy proposed by Shamos is very hard to attain. He calls it 'true scientific literacy' and involves both basic science knowledge and knowledge about the nature of science, such as the role of the experiment and evidence, logical thinking, and how to ask a well founded question, among other things (Shamos, 1995). Shamos does not consider participation in society or citizenship as necessary aspects of scientific literacy. Citizens can participate in the society without needing to attain 'true scientific literacy', for example, by trusting the experts.

Other science educators share Shamos' concerns about the personal and societal usefulness (or lack thereof) of the scientific literacy aspects embodied in science curricula. More to the point, some studies have explored whether people facing a situation where science plays an important role—such as a disease or the local management of radioactive waste—feel compelled to understand the underlying scientific principles and concepts. Results show that people are interested in the consequences and practical applications of science, but seldom do they show any interest in the concepts and theories that underlie those issues and from which the consequences of the application of scientific knowledge stem. (Solomon, 1994).

Bybee (1997) saw scientific literacy as a continuum within society, with opposite poles occupied by completely illiterate individuals and those fully literate. In-between would lie all manner of intermediate levels of knowledge and skill. The degree of literacy depends on various factors, such as age, experience, quality of education received, and personal circumstances. Along the scientific literacy continuum, Bybee established a number of thresholds or markers that categorise the degree of literacy of individuals: 'illiteracy' (failure to identify when a question is scientific), 'nominal literacy' (understanding when a question is scientific), 'functional scientific and technological literacy' (using scientific vocabulary in limited contexts), 'conceptual and procedural literacy' (understanding the relations among disciplines and how science works), and 'multidimensional literacy' (possessing a global, in-depth perspective of science and scientific activity).

Other authors have also proposed frameworks from which to define scientific literacy and what it means to be scientifically literate. All these frameworks are different from each other but, in general, agree that individuals should have some knowledge about basic science concepts, how science works, and what is its relationship with both society and technology (for an example, see Miller, 1983; Laugksch, 2000; Hodson, 2002). However, the emphasis of these frameworks on social participation is unequal. Some authors consider that, in order to function adequately in society, developing scientific thinking is even more important than knowing scientific concepts. Scientific thinking implies 'open-mindedness, intellectual integrity, observation and interest in testing their opinions' (Shamos, 1995, p. 80). For Norris and Phillips (2003), on the other hand, the most fundamental aspect needed to be scientifically literate is the skill to learn and read scientific texts, that is, 'comprehending, interpreting, analysing, and critiquing [scientific] texts' (p. 229).

For Zeidler, scientific literacy

> encourages practical knowledge of the nature of science, developing habits of mind consistent with positive scientific perspectives and attitudes, stressing scepticism and critical thinking, teaching for conceptual understanding of seminal linking themes and theories among the sciences, embedding science in cultural and historical contexts, and providing opportunities for students to generate their own meaningful questions and design approaches to investigate real world issues
>
> (Zeidler, 2001 p. 18-19 cited in Zeidler et al., 2003)

How best to include the notion of scientific literacy in a curriculum when there are so many definitions and approaches? In the late 1980s, science educators in the United States answered the question through the policy embodied by *Project 2061*, which, as was previously seen, emphasised scientific literacy. In this document it was mentioned that a scientifically literate individual should recognise the limits of the scientific enterprise and the knowledge it produces and be able to 'deal sensibly with problems that often involve evidence, quantitative considerations, logical arguments, and uncertainty' (American Association for the Advancement of Science, 1989, p. 13). These abilities, it was argued, would not only enable individuals to deal with everyday situations, but also function as citizens in society.

Given that the diversity of definitions, approaches, and goals ascribed to scientific literacy had rendered it useless, in 1996 the National Science Education Standards were proposed–in the United States—as a complement to *Project 2061*. These standards specified the characteristics that a student should have in order to achieve scientific literacy. According to these standards, scientific literacy is achieved when:

> a person can ask, find, or determine answers to questions derived from curiosity about everyday experiences. It means that a person has the ability to describe, explain, and predict natural phenomena. Scientific literacy entails being able to read with understanding articles about science in the popular press and to engage in social conversation about the validity of the conclusions. Scientific literacy implies that a person can identify scientific issues underlying national and local decisions and express positions that are scientifically and technologically informed. A literate citizen should be able to evaluate the quality of scientific information on the basis of its source and the methods used to generate it. Scientific literacy also implies the capacity to pose and evaluate arguments based on evidence and to apply conclusions from such arguments appropriately.
>
> (National Committee on Science Education Standards and Assessment and National Research Council, 1996, p. 22)

This definition emphasises the desirability of participation in society and decision-making processes. Unfortunately, and despite efforts to implement it, the goals set for this scientific literacy initiative were too broad and ambitious, making it difficult to implement in science classrooms (DeBoer, 2000). The project's report, *Science for All Americans*, justified the failure of the initiative by arguing that it is better to overestimate students than to expect little from them (American Association for the Advancement of Science, 1989).

Meanwhile, in the United Kingdom, the report *Beyond 2000: Science Education for the Future* (Millar and Osborne, 1998) evaluated the state of science education at the turn of the century and considered future perspectives. For the authors, a scientifically literate public, a requirement of democratic societies, is

> one with a broad understanding of major scientific ideas who, whilst appreciating the value of science and its contribution to our culture, can engage critically with issues and arguments which involve scientific knowledge. For individuals need to be able to understand the methods by which science derives the evidence for the claims made by scientists; to appreciate the strengths and limits of scientific evidence; to be able to make a sensible assessment of risk; and to recognise the ethical and moral implications of the choices that science offers for action.
>
> (Millar and Osborne, 1998, p. 4).

Donnelly (2005), however, differed from the underlying motives, focus, and curricular content for science teaching espoused in *Beyond 2000*: school science should not be expected to provide the capacity to make decisions in everyday situations or equip students with an intellectual toolkit with which to solve problems. For Donnelly, justification for the inclusion of science in curricula should rest on what distinguishes science from other kinds of knowledge, and students should be able to understand the 'intellectual coherency' of scientific knowledge and its 'power to predict and control' (p. 298).

What all the previous definitions of scientific literacy have in common is the difficulty of determining whether scientific literacy has been achieved. Since 2000, an effort to systematise the character and features of a scientifically literate individual, together with means of assessing and comparing outcomes among initiatives, was advanced recently as part of the Programme for International Student Assessment (PISA) evaluation. In the PISA studies, the international community agreed on a definition of scientific literacy that was subsequently used to design the test items. According to the OECD, scientific literacy is

> the capacity to use scientific knowledge, to identify questions and to draw evidence-based conclusions in order to understand and help make decisions about the natural world and the changes made to it through human activity.
>
> (OECD, 2003, p. 133).

The OECD document makes clear that the scientific knowledge mentioned in the definition is not only knowledge about science, but also an understanding of how science works and the limits of science. It considers an understanding of the world as an end in itself, but also as a necessary tool with which to make decisions. A novel idea, not included in previous definitions of scientific literacy, is that decisions concerning socially-relevant, science-related issues are conceptualised in a much broader context—apart from the scientific aspects, this context now includes social, political, economical, and personal aspects. The decision-making process should in principle be enriched by all those aspects, not just by science. These decisions range from the personal (for example, health and family) to the global level (for example, climate change and overpopulation) (OECD, 2000; OECD, 2003). This is particularly important in reference to the ultimate goal of education, that is, enabling individuals to live fulfilling and responsible lives (American Association for the Advancement of Science, 1989).

2.1.3. The Objectives of Scientific Literacy

As mentioned in previous sections, both the definition of, and the emphasis on, scientific literacy have changed over time. In some occasions, scientific concepts are given prominence; in others the relationships between science and society and how science works receive more attention. The objectives of scientific literacy have varied too, according to the different approaches proposed. These objectives range from the individual (*i.e.*, leading a fulfilling and responsible life) to the global (*i.e.*, achieving economical and social benefits for the country or the world). They also range from the ones that favour an appreciation of science for its beauty or because it is part of culture, to completely utilitarian ones, such as getting a better job.

Thomas and Durant (1987) have presented and discussed nine outcomes—commonly presented in the literature on the subject—that merit promoting scientific literacy. Each one of them represents a distinct focus or approach to scientific literacy. Some of them are more realistic than others, and the authors have criticised some of them on those grounds. The nine outcomes are as follows:

1. *Benefits to science:* Science benefits from scientifically literate individuals because, besides increasing the number of students that opt for careers in science, an informed public is more likely to support scientific research, both economically and ideologically. Furthermore, an awareness of how science works underlies an acknowledgement of the limitations of science and,

consequently, leads to realistic expectations about it. Thomas and Durant criticise this argument based on the fact that understanding science does not necessarily imply acceptance or support of it. On the contrary, people can oppose certain research projects even though they understand them. Acceptance or rejection depends not only on understanding, but on values and interests foreign to it.

2. *Benefits to national economies:* Scientific activity leads to innovation that represents an advantage for countries in the global marketplace. A high level of scientific activity can only be maintained with a sufficiently large number of scientists and technologists and an adequate support for science.
3. *Benefits to national power and influence:* Success in science brings with it political benefits derived from a high intellectual status and technological leadership.
4. *Benefits to individuals:* Scientifically literate individuals have more tools with which to decide about scientific issues that affect their everyday life, such as their health or their personal safety. Also, or so the authors argue, they can have better employment prospects.
5. *Benefits to democratic government:* In a democratic society, scientifically literate individuals have a more solid basis from which to make decisions about public policy related to science and, thus, are better decision makers.
6. *Benefits to society as a whole:* Scientific literacy facilitates integrating science to the wider culture—people stop feeling isolated from, or intimidated by, it.
7. *Intellectual benefits:* Science is an integral part of culture about which all informed citizens need to know.
8. *Aesthetic benefits:* This argument emphasises the creative aspect of science—understood as an achievement of the human mind and beautiful in itself.
9. *Moral benefits:* The values by which science is regulated could constitute an example for the rest of society. Thomas and Durant mention that this argument had fallen into disuse due to the negative social implications of some research projects.

Apart from Thomas and Durant's criticisms of the previous arguments for scientific literacy, other researchers have also taken issue with them. Millar (1996) has criticised the first three arguments—benefit for science, for the economy, and political—on the grounds that they can, ideally, be achieved by just promoting science as a career choice among students. Thus, none of these arguments justify why scientific literacy might be worthwhile for all students. Striking the balance between adequately teaching the few that will go on to scientific careers and teaching the majority that will not do so has always been a challenge for educators (Bybee, 1997)—with some researchers even disagreeing that such a distinction should be made (Donnelly, 2005).

That scientific literacy is useful in daily life has also been called into question (Millar, 1996): few, if any, real-life decisions require an actual understanding of science and how it works; most can be addressed by simple, easy to memorise, rules. What is more, even in those cases where an understanding of scientific knowledge would actually be of benefit, people appear to be uninterested in it (Solomon, 1994). In spite of the difficulty of ensuring that scientific literacy prove useful in an everyday context, Millar (1996) argues that this rationale is useful because it focuses attention on the science curriculum and in how to direct it towards technology-oriented aspects rather than more abstract ones. Donnelly (2005), in turn, argues that—in order to be able to evaluate the myriad socio-scientific issues an individual can face—he or she would need to understand in-depth many scientific ideas that cannot be properly covered in a science curriculum. Apart from that, acquiring the skills necessary to critique and decide upon socio-scientific issues is a long and difficult process. Even if some of those skills are acquired and developed, transferring or applying to different contexts is far from simple for individuals. Donnelly agrees with Shamos's (1995) view that, in practice, scientific and technical detail are best left to the experts.

Regarding the argument that posits political benefits to democratic societies, Millar (1996) observes that it is impossible to instruct students about all the issues that are currently debated, or will be debated in the future. That is why it is essential to define which are the fundamental ideas that students need to learn to then understand these kinds of issues—the task is daunting and, so far, it has not been achieved (Millar, 1996). Shamos (1995) summarises his position on how to prepare people to participate in a democratic society as a matter of answering questions such as: What should they learn? How to guarantee that what they learn will be useful in new scenarios that cannot be predicted? Which of those ideas of, and about, science are going to help students to make decisions?

While the intellectual and aesthetic benefits of science teaching are undeniable (science is, after all, one of the major achievements of culture), Millar (1996) argues that science educators are torn among three competing educational approaches, that is, teaching scientific advances either as fundamental facts of culture, as useful knowledge, or as examples of how science works.

Even when standards of scientific literacy have been set, these tend to be so broad and ambitious as to make it extremely difficult to translate them as a science syllabus. DeBoer (2000) equates the term scientific literacy with 'public understanding of science', which, by its very nature, must have a broad scope. He argues that we must accept this fact, instead of trying to define scientific literacy in a narrow and specific way.

How then to achieve the objective of helping individuals to become scientifically literate? How to determine whether they have achieved scientific literacy?

For Thomas and Durant (1987), scientific literacy does not consist of making scientific experts out of citizens, but rather training citizens to deal with science as encountered on a daily basis, enabling them to know and respect the work of scientists while at the same time being aware of its limitations and failures. This should then allow people to see science as a human enterprise, and grant it a role in their personal decision-making.

Several questions are suggested by the diversity of definitions, objectives, and approaches to scientific literacy (some of which, as already seen, are quite contradictory). How to achieve a measure of scientific literacy that allows individuals to participate in society in fulfilling and responsible ways? Is this outcome attainable? Is the knowledge of and about science useful for decision-making? Are there some aspects of scientific literacy that have more influence on decision-making than others? If so, which ones? Some researchers have studied the relationships between some aspects of scientific literacy (for example, content knowledge, the ability to analyse evidence, and the knowledge of the nature of science, among others) and decision-making. The next sections will address some of the aspects of scientific literacy that have been studied so far in their relation with decision-making, and what is their impact on the education of citizens that, through their decisions, actively participate in society.

2.2. The nature of science in science education

As discussed in the previous section, several educators agree that a scientifically literate individual must understand more than fundamental scientific concepts and theories, namely, ideas about the nature of science (NOS). The term 'nature of science' includes ideas drawn from the history, philosophy, and sociology of science and describes how science works, how is knowledge built and why it is reliable, the social structure of science and how it relates to society at large (Driver et al., 1996; McComas et al., 1998).

At the philosophical level, there are ongoing debates about several aspects of the NOS. However, at the educational level, there is broad consensus on the most relevant aspects of the NOS that students should know and understand (McComas et al., 1998). Owing to this consensus, it has been possible to include aspects of the NOS in curricula of different educational levels in several countries, including Mexico and the United Kingdom.

The aspects of the NOS that are considered to be the most relevant by science educators, and about which a consensus has been reached, are listed in Table 1.

Table 1 Important aspects of the NOS for science education (from McComas et al., 1998, p. 6)

- Scientific knowledge while durable, has a tentative character.
- Scientific knowledge relies heavily, but not entirely, on observation, experimental evidence, rational arguments, and scepticism.
- There is no one way to do science (therefore, there is no universal step-by step scientific method).
- Science is an attempt to explain natural phenomena.
- Laws and theories serve different roles in science, therefore students should note that theories do not become laws even with additional evidence.
- People from all cultures contribute to science.
- New knowledge must be reported clearly and openly.
- Scientists require accurate record keeping, peer review and replicability.
- Observations are theory-laden.
- Scientists are creative.
- The history of science reveals both an evolutionary and revolutionary character.
- Science is part of social and cultural traditions.
- Science and technology impact each other.
- Scientific ideas are affected by their social and historical milieu.

In principle, understanding these aspects of the NOS would enable people to distinguish scientific knowledge from other kinds. It would also make it easier for students to understand how knowledge claims are related to one another (for example, theories with laws) and why they can change. Studying the human face of science can help promote in students an understanding of why science is immersed in culture and intimately linked with the society that supports its continued existence. Likewise, understanding the NOS would allow citizens to possess more solid foundations upon which to define their views concerning socio-scientific issues encountered in daily life (McComas et al., 1998).

There is some evidence pointing to the fact that, in practice, teachers and students possess naïve, difficult to change, views of the NOS. In the following sections, these ideas will be briefly presented and discussed, together with the efforts done to teach the NOS and the results obtained so far. Still later, whether there is a relationship between views of the NOS and how decisions are made regarding socio-scientific and pseudoscientific issues will be discussed.

2.2.1. Views of the nature of science

Research on students' and teachers' views of the NOS has relied on different conceptual approaches to the NOS and diverse assessment instruments. Both have changed over time. Initial efforts used paper-and-pencil assessments that addressed both ideas about science and scientific inquiry skills and attitudes toward science and scientists. These studies focused almost exclusively on the views of students, without exploring their underlying causes or what their consequences might be. Subsequently, the distinction between topics belonging to the NOS and those that belonged to skills and attitudes became clearer. Assessment instruments also became more diverse, incorporating open-ended questions and one-on-one interviews that allowed probing students' views with more depth and attenuated the effects of the prejudices of researchers. These kinds of strategies, however, limited the application of these instruments to small groups of respondents (Lederman, 1992).

Regardless of the approaches and the methods used to assess students' views, the earliest studies suggested that students of all ages and educational levels had naïve views of the NOS. Unfortunately, more than half a century after the first formal assessment of students' views, the overall majority of studies coincides on one thing: in spite of the more or less explicit inclusion of the NOS in syllabi worldwide, students keep having a naïve understanding of the NOS (Lederman, 2007). Several investigations have shown that views of the NOS are relatively independent of science content knowledge, grades obtained in science courses, and skills of logical thinking and their ilk, among others (Khishfe and Abd-El-Khalick, 2002).

This section does not pretend to be an exhaustive account of research on the history of students' views of the NOS, nor of the development and use of assessment instruments, but rather a compendium of the more common ideas of the NOS found in students responses. A summary of those ideas is presented in Table 2

Table 2 Common views of the NOS held by students (from Gilbert, 1991; Lederman, 1992; Solomon et al., 1992; Driver et al., 1996; Khishfe and Abd-El-Khalick, 2002; Abd-El-Khalick and Akerson, 2004; Lederman, 2007).

- Scientific knowledge is not tentative.
- Scientific knowledge is true and incontrovertible.
- Scientific knowledge is objective.
- Theories are facts.
- Theories are just 'somebody's idea' of what might be going on.
- Observations are independent of theory.
- The aim of science is to collect and classify facts.
- An accumulation of empirical evidence proves that theories are true.
- Science develops in a linear and systematic process.
- Experiments are useful to make discoveries.
- Experiments are like 'shots in the dark', that is, they are not guided by theory.
- In science, building models depends on, and is guided by, the laws of logic.
- Science is not creative.
- The aim of scientific knowledge is to discover theories and laws of nature.
- Science is characterised by a unique, correct method: the scientific method.
- Theories become laws once they are proved.
- The aim of science is to solve the problems of society.
- Disagreements among scientists are due to lack of knowledge or experimental errors.
- Disagreements among scientists are due to personal and professional interests.
- Scientists are free from the influence of their social and cultural milieus.
- Theories are dependent on the personal beliefs of scientists and independent of empirical observation.
- Scientific controversies are due to lack of data.
- The aim of science is to produce technology.
- Science and technology are the same thing.

Once identified, these common ideas that students appear to believe about the NOS have served as targets for instruction in the hope of developing in students more nuanced and sophisticated views that agree with the consensus mentioned in the previous section.

2.2.2. Efforts to change students' and teachers' views of the nature of science

Teaching ideas of the NOS has to overcome the obstacle represented by students' lack of familiarity with actual scientific activity—as performed in research laboratories and university departments. This lack of direct, hands-on experience means that students' picture of science is mostly drawn from school science and the image propagated by the mass media (Driver et al., 1996). Furthermore, it has been found that teachers' views of the NOS are not much better than students'—certainly not adequate. Furthermore, teachers with sophisticated views—rare though they may be—fail to impart an adequate picture of the NOS to their students (Lederman, 2007). Individuals' views of the NOS are very difficult to change with a single educational intervention—they are the product of many years of exposure to naïve ideas about science.

What remains of this section will be devoted to an account of some of the efforts that have been made to change individuals' views of the NOS. Besides exploring interventions designed to improve students' views, those intended for science teachers—in many cases preservice or trainee teachers that have yet to conclude their bachelor's degree—will be discussed. Findings and insights from this last kind of intervention, directed as they are to adults with some background in science, can be transferred to a population of university science undergraduates. They thus represent a wider range of strategies for the teaching of the NOS and enrich the framework of analysis.

Broadly speaking, in the literature on the subject there are two approaches to the teaching of the NOS. The first assumes that individuals will improve their views if they are exposed to the history of science, scientific research activities, or contact with actual scientists. In this approach the features of the NOS are not explicitly emphasised, and in some cases are not even mentioned—a so-called 'implicit' approach. In the second approach the views of the NOS are explicitly emphasised for the benefit of students, and their discussion and use as tools for analysis is promoted—an ‘explicit approach’ (Khishfe and Abd-El-Khalick, 2002). In the following paragraphs, some examples of both approaches, together with their results and limitations, will be discussed.

Abd-El-Khalick and Lederman (2000) researched the views of 166 undergraduate and graduate students and 15 preservice secondary science teachers before and after taking part in courses on the history of science. The authors argued that, in order for it to be successful in promoting adequate views of the NOS, a course on the history of science must, among other things, invite participants to put on ‘a different kind of thinking cap’, that is, situate themselves in a particular historical context, so as to avoid judging information and events from a modern standpoint.

The authors assessed the outcomes of four different courses: Scientific Controversy (dealing with controversial scientific discoveries), History of Science (a brief historical account of science, focusing on the social and cultural context), Evolution and Modern Biology (about the origin of the theory of evolution), and a course on teaching strategies and methods (group management, lesson planning, assessment models). The courses lasted for a semester, three hours a week. When interviewed, course instructors stated that one of their aims was to impart an understanding of the processes of science. The only instructor that talked specifically about the NOS was the one responsible for the Evolution and Modern Biology course. However, apart from this brief mention of the NOS, none of the other courses taught it explicitly (Abd-El-Khalick and Lederman, 2000).

Students’ views were assessed before and after the course through an open ended questionnaire and semi-structured interviews. Their views on the tentativeness of scientific knowledge, its empirical basis and inferential nature, and the role played by creativity and subjectivity were explored. At the beginning, students’ views with regards to all these topics were naïve, even though preservice teachers exhibited slightly more developed views compared with college students. At the end of the course, students’ views remained mostly unchanged, and the few that did change were limited to one or two aspects of the NOS. A noteworthy result was that, apparently, trainee teachers, who initially had more sophisticated views, improved their views more than students did. This suggests that previous ideas played a significant part in the assimilation of ideas of the NOS (Abd-El-Khalick and Lederman, 2000).

The authors concluded that, when the history of science is taught as finished narratives and students do not put themselves in the place of past scientists, reflection about the NOS is stunted and it is unlikely that students will develop sophisticated views about it (Abd-El-Khalick and Lederman, 2000).

In another study that explored the influence teaching the history of science has on views of the NOS, a group of Taiwanese teachers was trained in how to teach chemistry with the aid of the history of the chemistry. The authors evaluated the views of 63 prospective chemistry teachers (completing the last year of their training programme) before and after the course. Their views were then compared with first-term students. The authors warned that the control group they had chosen was not the ideal one, but was the only one available to them. However, the comparison between both groups was deemed valid—or so the authors argued—since the initial views of both groups were similar enough and the control group received no instruction on the topic of the intervention. Teachers' views about creativity in science, theory-ladenness, and the role of theories in science were evaluated (Lin and Chen, 2002).

The history of chemistry course comprised materials describing how chemists had achieved some sort of understanding of some phenomena, as well as a variety of activities—readings of historical debates, discussions, demonstrations and experiments. However, ideas about the NOS were not explicitly discussed in any of the activities. At the end of the course, students had improved their views of the NOS compared with the control group (in topics such as discovering versus inventing theories, the relationship between theories and laws, and the predictive role of theories). However, their views of any other aspect did not change at all (Lin and Chen, 2002).

In both of the aforementioned studies, it appears that history courses in which the NOS is not made explicit—even though valuable for teachers—are not useful to develop views of the NOS.

Another strategy employed to develop views of the NOS consists of making students participate in science-related activities with actual scientists. Moss et al. (2001) evaluated the views of five pre-college students in a class of Conservation Biology. In this class students worked together with several scientists in four different environmental protection projects throughout the whole school year. The main source of data was a series of interviews with the students, complemented with written materials produced during the course. The authors of the research claim that at the beginning of the course students exhibited more sophisticated views of the nature of scientific knowledge than of the nature of scientific activity. The example referred to in support of this claim is that none of the participants recognised the role played by serendipity in science, but some did recognise the role of evidence in research. In spite of having these more or less developed views and the contact with scientists, students did not show any change at the end of the school term.

It is worth mentioning that the authors of the study relied on interviews to determine the views of the NOS, and not a previously validated assessment instrument. Issues involved in the selection of interview topics and questions, as well those having to do with the particular interpretations made by researchers could account for the differences found in students' views—more sophisticated than those normally found in students of that age. However, comparison between the views of students at the beginning and the end of the course lend some credibility to the findings, since the same assessment instrument was used in both occasions.

Another research group explored whether the views of the NOS changed in preservice teachers while taking a course on science methods. As part of the coursework, students had to embark on research on the phases of the moon, making observations and finding patterns. The authors intended that, with such a course, teachers would learn that science is empirically-based, involves creativity when coming up with explanations, and is immersed in a social context. However, these objectives were not told explicitly to participating teachers and neither were activities enacted that addressed those aspects of the NOS (Abell et al., 2001).

Students in the course recognised that in their research of the moon they had identified patterns and invented explanations. They also became aware of the social influence in the building of knowledge. However, they were unable to transfer the personal experience gained about these issues of the NOS to the wider scientific context and neither were they able to modify their initial views of the NOS (Abell et al., 2001).

The educational conclusions to both studies in which individuals participated actively in research and the creation of knowledge point to the fact that an implicit approach to the teaching of the NOS has little to no impact on students' views.

Carey et al. (1989) also used inquiry and hands-on activities to try to improve the views of the NOS of 12-year old students. The main difference with the aforementioned studies was that they made explicit the views of the NOS, especially the role of experiment and theory in science. The authors designed two teaching units: one about the NOS and one about research on bread and yeasts. In both lessons students discussed, and reflected upon, aspects of the NOS. In general, a slight improvement in students' views, compared with their original ones, was observed—students were able to recognise that experiments have a purpose defined by theory and experiments are not just 'shots in the dark'. Students also improved their ability to discriminate between explanations and facts.

On the other hand, Solomon et al. (1992) showed that an historical approach to the teaching of the NOS can have an effect on students' views, as long as these ideas are made explicit and students are given the chance to reflect on them. The authors extracted short stories from the history of science that emphasised the construction of new concepts. The teaching units were complemented with laboratory activities. This study is noteworthy because it represented a continuous and sustained teaching effort, with five teaching units distributed along a one-year term, at the end of which students said that the aim of experiments is to test explanations—a notable improvement in the appreciation of the role that theory plays in experimentation and prediction. The difference between theory and fact was also better appreciated.

Based on the work of Solomon (1992), Tao (2003) adopted a historical approach for his research on the effect of a story-based educational intervention. Views about science were explicitly discussed in accounts from the history of science that secondary school students were given to read. However, the views were not discussed in class. At the end of the course, students accepted that experiments are used to test explanations, but failed to recognise that scientists can make predictions about what results to expect or that facts and scientific theories are two different things. The author argued that students read the stories from their own personal perspectives and selected as relevant only that information that matched their own pre-existing views about science.

In spite of the fact that the ideas of the NOS were addressed and explained in the stories, in this work students were offered no opportunity to discuss them amongst themselves or with their teacher. Previous ideas about the NOS are difficult to change, and if students have no opportunities to reflect and challenge them, the results of interventions tend to be poor.

In Mexico, a study with 11 in-service science teachers, enrolled in an MA degree in science teaching, was conducted to determine the effect of coursework on their views of the NOS. One of the teaching modules (10 hours duration) presented readings of selected topics from the philosophy of science. The report of the study, however, was not clear on whether participating teachers had any opportunity to discuss the information read or which kinds of activities took place in the module. At the end of the 10 hours, students had improved slightly their views of the NOS, shifting from a positivist outlook to a more relativist one. However, teachers still failed to achieve a coherent NOS profile (Barona et al., 2004).

The results of these studies suggest that, whether or not a historical approach or scientific inquiry activities are adopted, the most important strategy to achieve a change in students' views of the NOS is making them explicit and inviting students to reflect upon them.

To determine the difference between an implicit approach and an explicit one in the teaching of the NOS, Khishfe and Abd-El-Khalick (2002) evaluated the views about the tentativeness, the empirical basis, and the role of imagination and creativity held by 62 eleven-year old students, who answered a questionnaire with open-ended questions, as well as one-on-one interviews, both at the start and the end of a 2.5-month long intervention. Students were divided in two groups: both carried out six inquiry activities, working in small teams and discussing amongst themselves all aspects of the activity. The only difference between the groups was that, with one of them, the instructor emphasised explicitly those aspects of the NOS that were pertinent to the activity and invited students to reflect upon them (Khishfe and Abd-El-Khalick, 2002).

Before the course, students in both groups had similar naïve views about the NOS. At its end, students in the explicit treatment group had improved their views of the NOS, compared with the implicit control group. However, students of both groups exhibited difficulty in understanding the role of imagination and creativity in science (Khishfe and Abd-El-Khalick, 2002).

In order for students to develop sophisticated views of the NOS, it is necessary, among other things, that teachers possess these kinds of views themselves. As previously mentioned, science teachers do not possess sophisticated views of the NOS. That is why the same researchers explored the change in the views of the NOS of a group of preservice elementary teachers enrolled in a Science Methods course. These teachers were both undergraduates and college graduates. In the course, several aspects of the NOS were explicitly incorporated into all the activities, and discussed at length with the instructors, who provided the opportunity to do so. The initial views of the NOS of graduates and undergraduates were slightly different: the former had adequate views about the empirical and tentative nature of science, while undergraduates had adequate views about the role of creativity and imagination in science. All students had naïve views about one or several aspects of the NOS (Akerson et al., 2000).

At the end of the course, students had improved their views of the NOS, especially about the tentative nature of science, the difference between observation and inference and the relationship between scientific theories and laws. However, few participants exhibited a sophisticated and coherent view of all aspects of the NOS as well as being capable of connecting one aspect with another (Akerson et al., 2000).

The authors of the study argued that the course did not invite teachers to explore their initial views, something that could have influenced negatively the change in the conception of the NOS. In their follow-up study, they put in practice an intervention that made explicit teachers' initial views of the NOS, based on a conceptual change model. In such a model, individuals revise their ideas about a topic when they are challenged by the activities of the intervention. The 28 participating teachers enrolled in a course of Elementary Science Methods. These teachers intended to obtain a BA degree in elementary education, which is why they already had a scientific background. After reflecting upon their ideas of the NOS, participants carried out a series of activities intended to challenge them to re-evaluate their views on the topic. Compared with their previous study, the authors concluded that a higher number of students achieved adequate views of the NOS (Abd-El-Khalick and Akerson, 2004).

Even though an individual can be seen to improve his or her views of the NOS, this does not imply that he or she is able to transfer them to other contexts—for instance, from situations seen at school to novel ones from everyday life. Using the same explicit NOS intervention previously used, Abd-El-Khalick (2001) evaluated the final views of chemistry teachers when facing a familiar and a novel context. At the end of the intervention their views improved slightly, but participants still could not apply their knowledge of the NOS to unknown contexts (the extinction of the dinosaurs) compared with familiar ones (atomic structure).

In previous studies, an explicit approach that provides the opportunity for discussion about students' own views and what the desired views are tends to improve views of the NOS. However, difficulties remain: many students find it hard to transfer their knowledge to novel contexts, which suggests that they have not fully interiorised the adequate views of the NOS and are unable to generalise. It also has not been tested whether adequate views are stable. For a citizen to be scientifically literate, it is not enough that his or her views prove to be adequate in a test, but that he or she be able to use these views in a variety of contexts to make informed decisions.

2.3. The socio-scientific issues movement and decision-making

As discussed in the previous section, it is not desirable to separate school science content from its application or use in a variety of contexts, or from its implications. Students need to familiarise themselves, while in school, with useful applications of the NOS to everyday situations (Osborne and Collins, 2000). In this way, science content can contribute to improve social participation of students (Zeidler et al., 2003).

A large part of the scientific research currently underway has (or will have) an impact on the lifestyles of citizens. Examples of relevant socio-scientific issues are genetically-modified organisms, alternative sources of energy, the use of pesticides, vaccination, global warming, and the food crisis. These issues in which science and society affect one another have been called—by part of the educational research community—socio-scientific issues (SSI), and their actual impact on society at large varies—from individual decision-making all the way up to the drafting of public policy (Martin and Richards, 1995; Ratcliffe and Grace, 2003; Sadler, 2004).

In large part due to modern mass media and information technologies, today's controversies arising from socio-scientific issues are readily available—and in detail—for scrutiny. One consequence of this state of affairs has been the widespread realisation, in the populace, that even among scientific experts there are disagreements in how to assess the validity of scientific theories, for instance. These disagreements can be due to epistemological matters (such as differing interpretations of the same data), economic and/or political interests, or, even, to moral or ethical judgments of the experts themselves. With increasing frequency, society discovers that seeing experts' claims as either infallible, objective, or neutral is a fallacious and untenable notion. Awareness of the existence and nature of these kinds of disagreements has given rise to increasing distrust towards experts' opinions in certain sectors of society and to questions about who is in control of scientific decisions concerning what is researched and how is knowledge applied. This awareness, together with the moral and ethical implications associated with the application of scientific knowledge, has led to the widespread, popular demand for opportunities to participate in decision-making where scientific matters are concerned (Nelkin, 1992; Martin and Richards, 1995; Oulton et al., 2004).

Given that a democratic society has to engage with decisions that deal with socio-scientific issues, these have been considered an essential part of scientific literacy. For this reason, several science educators have advocated including socio-scientific issues as part of science curricula (Pedretti, 1999; Hughes, 2000; Sadler, 2004; Sadler and Zeidler, 2005).

Due to their nature, SSI and decision-making are closely connected. Indeed, that is why it is no surprise that curricula explicitly linking science teaching and decision-making existed even before SSI had even been properly defined within an educational setting.

As early as the 1930s, the notion that science education should provide students with the skills required to make informed decisions was discussed and advocated. However, there was a tinge of naïveté in the proposition that these decisions had to be guided solely by scientific thinking, a kind of thinking defined by, among other things, a reasoned assessment of evidence free from emotional or external bias (Shamos, 1995). Currently, science curricula tend not to include this objective. On the contrary, present educational trends take science to be one of many factors that come into play when making a decision, one that cannot be made without involving values and interests.

Recent policy reform documents emphasise that, as part of scientific literacy, students should be capable of making informed decisions about socio-scientific issues that directly affect their everyday lives. Likewise, students should be able to adapt to a changing world increasingly dependent on science and technology (Murcia, 2009). The American reform document ‘Science for All Americans’ states that the contents of science syllabuses should be selected according to whether they: a) prove useful for making personal decisions; b) allow students to make informed decisions in matters of social and/or political relevance that involve science and technology; c) have intrinsic cultural value; d) allow students to reflect on philosophical aspects, such as the meaning of life, death, or the perception of reality; and e) enrich childhood (American Association for the Advancement of Science, 1989). The first two criteria highlight the need scientific contents need to fulfil—assist decision-making at the personal, social, and political levels.

On the other hand, in the United Kingdom, Millar and Osborne (1998) have suggested that science education ought to aspire, among its objectives, to help students in their daily decision-making, for example, in choosing what they eat, which medical treatments are best, and how to save energy. They have also emphasised that students should be made aware that decision-making processes—even those science-related—imply, besides scientific knowledge, other kinds of considerations such as economic, social, environmental, and technical ones, and, no less important, those that have to do with ethical, political, or religious matters.

Decision-making skills and tasks can only be addressed adequately—and in a relevant manner—in the context of scientific issues that demand public attention. The Science-Technology and Society (STS) movement has advocated one of the most popular approaches for introducing SSI into the classroom. However, the STS movement has been criticised on several points.

In the last few years, the STS movement has been criticised—among other things—for its theoretical ambiguity. Several authors have pointed out that it lacks a coherent and unified theoretical framework, something that has invited the proliferation of several approaches, each one with diverging interests and objectives, under the umbrella of Science-Technology-Society. One of the main criticisms against the STS movement focuses on the perceived lack of relevance of the contents for students' everyday life—for example, in the treatment of nuclear energy. Even more importantly, STS approaches do not emphasise ethical aspects implicit in decision-making and in the moral or character development of students (Zeidler et al., 2005). Hughes (2000) has criticised some of the curricula that have incorporated an STS approach because they are drawn out in such a way that the social content involved in decision-making can easily be overshadowed by scientific content. She claims that these kinds of courses do not fulfil the task of breaking away from the dominant scientific discourse, one that privileges abstract knowledge and denies any role for science within society.

The socio-scientific issues (SSI) movement came into being in response to the criticisms against the STS movement. Compared with the STS movement, the SSI movement seeks to promote the moral and ethical development of students—a necessary step towards facing personal and social choices posed by science—and not only use contentious scientific issues as context for science teaching. According to its promoters, the SSI movement is a pedagogical strategy that fulfils the established standards of policy reform documents, since it compels students to make decisions about scientific issues while appreciating that these decisions draw not only from science-related aspects but also from moral and social ones (Zeidler et al., 2005).

When students engage with an SSI pedagogy, they face moral and ethical dilemmas that involve science and that, importantly, can conflict with their personal views and ideas (Zeidler et al., 2009). This invites students to interact amongst themselves and discuss the ethical aspects of a scientific topic while building a moral judgment (Hodson, 2002; Zeidler et al., 2005) and appreciating the degree of interaction between science and their everyday lives (Pedretti, 1999; Driver et al., 2000). Since the issues are relevant for students and involve a deep analysis of the different aspects of the same situation, the resulting knowledge from engaging with an SSI will be both meaningful and relevant (Zeidler et al., 2009).

In his review of the literature about SSI up until 2004, Sadler concludes that SSI 'can provide a forum for working on informal reasoning and argumentation skills, nature of science (NOS) conceptualisations, the evaluation of information, and the development of conceptual understandings of science content' (Sadler, 2004, p. 533). Additionally, learning to assess and solve these kinds of complicated situations is a necessary skill for fully participating in a democratic society (Pedretti, 1999; Kolstø, 2001).

Ratcliffe and Grace (2003) analysed several examples of SSI and concluded that they have the following broad characteristics:

Table 3 Characteristics of SSI (from Ratcliffe and Grace, 2003, p. 2-3).

- Have a basis in science, frequently that at the frontiers of scientific knowledge;
- involve forming opinions, making choices at personal or societal level;
- are frequently media reported, with attendant issues of presentation based on the purposes of the communicator;
- deal with incomplete information because of conflicting/incomplete scientific evidence, and inevitably incomplete reporting:
- address local, national and global dimensions with attendant political and societal frameworks;
- involve some cost-benefit analysis in which risk interacts with values;
- may involve consideration of sustainable development;
- involve values and ethical reasoning;
- may require some understanding of probability and risk;
- are frequently topical with a transient life.

None of the SSI characteristics can be dealt with unequivocally or addressed with a unique 'correct answer'. That is why assessing and adopting an opinion about SSI is not easy or straightforward. Sadler and Zeidler (2005) have named those processes involved in assessing SSI 'informal reasoning'. Contrary to the formal reasoning used to solve mathematical problems, where the conclusion is logically derived from the premises, informal reasoning leads to conclusions that are not evident at the outset and can change according to circumstances. When respondents evaluate the pros and cons of an SSI, they balance the risks and benefits or study possible alternatives of solution, they are engaging in a process of informal reasoning (Sadler, 2004). This process includes the affective processes as well as cognitive ones that students draw upon when solving an SSI (Sadler and Zeidler, 2005).

Teaching students how to solve SSI is no easy task by any means due to the large number of elements in play. Besides acquiring scientific knowledge, students must develop various skills, such as those critical skills with which to assess scientific evidence, find relevant information, assess its sources, keep a measure of scepticism, among others. Nevertheless, that is not enough and students must learn to assess SSI from the social, ethical, and moral perspectives (Zeidler et al., 2005). Even in science classes, teachers must be aware that solving SSI involves non-epistemic factors, such as cultural, social, political, and religious beliefs, as well as emotional factors and values (Acevedo-Díaz, 2006).

When dealing with contested issues in the classroom, it is well worth emphasising that different groups of people can have widely divergent viewpoints owing to several factors like the information available to them, how they interpret it and how it meshes with their particular worldview and values. This facts do not imply that all views are of equal worth; however, students must learn that alternative viewpoints can be valid, even though they might differ from theirs. Likewise, teachers must emphasise that in order to solve SSI, logic and reason are not always the only resource and that it is possible that in some cases, more information could solve the controversy. Unfortunately, several studies suggest that many science teachers continue to teach as if science were an incontrovertible truth, objective, neutral and isolated from the rest of society (Oulton et al., 2004).

In order to improve the teaching of science through the SSI approach it is necessary to understand how students analyse SSI and make decisions about them. There have been many studies concerning this topic that will be touched upon in the following sections.

It is worth pointing out that when research about decision-making on SSI is carried out, assessment tools whose output consists of opinions—not of decisions—are relied upon. There is a difference between both terms, owing to the differing degrees of commitment required of the individual making the decision. This notwithstanding, the majority of researchers use the word ‘decision’ to name these opinions (Grace and Ratcliffe, 2002) and that is the use that will be given to the word in the following pages.

2.3.1. Research on SSI: How are SSI understood, evaluated and decided upon by students?

SSI are, by definition, complex; their assessment and resolution involves knowledge of and about science, but also social, political, economic, religious, and ethical aspects must be taken into account. As has previously been mentioned, SSI do not have a straightforward solution and there is no predetermined method for their resolution. That is why research on how students deal with SSI is also complex. Different researchers focus on different aspects of SSI when evaluating how students negotiate and solve SSI—for instance, how they argue, how they use their previous knowledge, what is the relationship between their reasoning and their views of the NOS, among others.

Models generated to evaluate how students assess and solve SSI vary from those with a broad and general scope to very specific ones that describe how students use certain skills, knowledge, and attitudes to solve specific aspects of SSI. Among these models there are those that are highly descriptive, drawn from research, as well as normative ones where researchers come up with aspects students should in principle consider to better solve SSI. The relevance of generating models with the ability to describe how students negotiate SSI lies in that they help us to understand what students value, how they reason, and what aspects they evaluate of problems of this type. Being aware of this is useful in the design of pedagogical strategies focused on SSI and in the design of science curricula (Sadler and Zeidler, 2005).

In this section, only the general models about how students evaluate and solve SSI are described, that is, models that do not focus on one specific area or domain involved in solving SSI, such as argumentative skills, the relevance of previous scientific knowledge, and viewpoints about the NOS, among others. These studies will be addressed in detail in future sections. Three distinct models—proposed by the same research team—will be described in detail. The first two were based on research done by the authors while the third was adapted from another model to evaluate problem-solving skills and then applied to evaluate interventions involving SSI.

Sadler and Zeidler (2005) investigated which are the patterns of informal reasoning that students rely on when assessing SSI. They devised and used a series of scenarios about genetic engineering and evaluated the responses of thirty college students to these scenarios. From the analysis of responses they then derived the patterns of informal reasoning of students. They found that students use mainly three kinds of informal reasoning that they called *rationalistic*, *emotional*, and *intuitive*.

When using rationalistic informal reasoning, students provided arguments based on various factors, such as rights and obligations of those involved in the controversy at hand; they analysed alternative options of solution; they weighed the consequences of one or another decision. Emotions did not have an important role in this kind of reasoning. Emotional informal reasoning was very common among students. It is based on emotions such as sympathy and empathy, that is, students had particular interest in one or more of those involved in the controversy or, alternatively, were able to put themselves in the place of those involved. By intuitive informal reasoning the authors refer to an unjustified or visceral response from students, generally a result of an immediate reaction to the situation under discussion. This is the type of reasoning that was less used by students but, nevertheless, researchers found that when it was used it strongly influenced decisions. Generally, researchers found that students did not use only one kind of reasoning to deal with an SSI, but two or three. The different types of reasoning used by students in a given situation were not always coordinated; frequently, they conflicted with each other (Sadler and Zeidler, 2005).

This model is very broad and its categories group specific aspects students take into account when making a decision, for example, their personal experiences, social and/or moral issues related to the SSI (Sadler and Zeidler, 2005). This model analyses how students reason at all levels, rational, emotional, and intuitive, and its intended outcome was not to develop hierarchies of any of these levels, something that would have enabled the researchers to differentiate between naïve and sophisticated responses. Two years later, one of the authors of the model undertook research to determine the characteristics of rational informal reasoning of students.

In order to help understand how people evaluate and arrive at a conclusion concerning an SSI, Sadler et al. (2007) proposed a theoretical construct called *socioscientific reasoning*. Even though the authors make no mention of it in their research paper, it seems that this 'socioscientific reasoning' is in fact the 'rational informal reasoning' mentioned in the first model. This second construct is of a descriptive nature, possesses an empirical basis, and it is modelled from what the authors take to be the most important practices students engage in when making decisions about an SSI. These practices are:

a) *Complexity:* Students recognise that SSI are complex problems that do not have a definite answer and involve complex interactions amongst agents with different interests and opinions.
b) *Perspectives:* Students recognise that different, well-supported viewpoints can be adopted about the same problem.
c) *Inquiry:* Students recognise that SSI are real problems in which information may be lacking, whether because the issue is at the cutting edge of science (science-in-the-making) or because its environmental, social, economic, and political costs are yet unknown.
d) *Scepticism:* Students recognise that the various agents involved have interests that influence the information they receive. Students are thus able to identify possible biases or limitations in the analysis of evidence.

In order to make socioscientific reasoning a functional theoretical construct, its authors devised a rubric that assigns to each practice a number from 1 to 4, depending on the degree of sophistication of the response. They applied this rubric to responses from sixth grade students that solved two different scenarios (pollution and water quality). The analysis yielded a normal distribution in which the majority of students provided intermediate responses (that is, corresponding to values of either 2 or 3 in the scale) with few providing responses deemed too simple or naïve and even fewer responses the authors thought sophisticated (Sadler et al., 2007).

This construct consists then of only four categories or practices and does not take into account other practices that might be considered part of the rational informal reasoning of students, such as what kinds of previous knowledge or values are used to deal with an SSI. The construct also fails to mention how students evaluate scientific evidence, an important part of the analysis of SSI. It is worth mentioning that many of these practices are highly dependent of the context of the SSI and can be thus difficult to assess and generalise. For instance, a student might already possess some knowledge of a given topic and so influence his or her assessment of an SSI, compared with students without this previous knowledge. The framework of socioscientific reasoning also fails to consider students' knowledge of how science works.

Another further limitation of the socioscientific reasoning framework lies in its definitions—the ones for 'complexity' and 'scepticism' indicate that students should be able to appreciate the role, interests, and motivations of different agents in the issue. This superimposition of categories can impair the analysis and make it redundant. Likewise, the term 'scepticism' can be misleading—a student can be doubtful of data and consequently ask for a justification because he or she suspects that external interests might be involved, but he or she can also have a genuine epistemological concern, that is, he or she might want to know how a given evidence was generated or has been justified. In spite of its limitations, the usefulness of this framework lies in it being an effort to understand how students deal with SSI, a necessary step towards finding out if there are recurring patterns of reasoning among different contexts and assessing the effectiveness of educational interventions.

Two years later, the same research group studied how the way students analyse SSI changes after a full year of taking a course that emphasised these kinds of issues (Zeidler et al., 2009). To back up their claims, the authors used four groups of students taking an anatomy college course: two control groups followed a traditional syllabus and two treatment groups followed a syllabus especially designed to include the SSI approach. Even though the authors had proposed two previous models or frameworks about how students analyse SSI (the patterns of informal reasoning and 'socioscientific reasoning'), for this study they did not use any of them, but instead relied on a model called 'reflective judgment model' developed by King and Kitchener (1994; cited in Zeidler et al., 2009). This model also is empirically-based and was designed with the aim of investigating how the skills of students with which they deal with complex issues change in an age-related manner or after an intervention. It is worth mentioning that the reflective judgment model was not explicitly designed to study SSI. However, these issues are also complex problems without an established or straightforward answer. This is the rationale presented by the authors for adapting the model to their needs. This model considers that individuals go through seven different stages, each one more sophisticated than the previous, when they solve problems. These seven stages are grouped in three general categories that described in detail in what follows.

The first category corresponds to *pre-reflective thought*, and individuals that occupy the stages grouped in this category tend to assume that there is only one absolute truth dictated by a figure of authority (that can be any person with more power or knowledge than the individual). People in this category lend more credence to authority than evidence. The second category comprises the *quasi-reflective stages*. An individual that occupies these stages questions his or her system of beliefs and accepts that authorities can be wrong or even lie. However, these individuals still do not clearly know how to unequivocally define a stance towards an issue. Generally, people in this category tend to be cynics because they believe that evidence is there to back up preconceived ideas instead of actually contributing to knowledge. Even though they can appreciate different points of view, they seem unable to establish a coherent framework from which to make decisions. Finally, the third category corresponds to the *reflective stages* in which individuals allow evidence and arguments to influence their thinking. Likewise, they possess more sophisticated viewpoints about the NOS and recognise experts as authorities that generate knowledge that can contribute to solving a problem. They also accept that knowledge can change, while also being able to weigh different alternatives (Zeidler et al., 2009).

As can be seen from these categories, the reflective judgment model is analogous to the development of students' views of the NOS, whereupon a naïve view initially tends to dominate, a view that paints science as authoritarian and knowledge as immutable. As the views of the NOS progress and become more sophisticated, students understand the role of evidence in the construction of knowledge and what is the role of scientists in this process (Zeidler et al., 2009).

In Zeidler and co-workers' (2009) study, students that followed the syllabus based on SSI showed a clear progression through the stages of judgment comprised by the framework, compared with students that followed the traditional syllabus. The authors conceded that their sample was relatively small and their study was limited by practical considerations. However, results suggest that is feasible to improve the processes by which students evaluate and decide upon SSI.

The fact that even Zeidler and co-workers themselves have proposed three different models with which to investigate how students make decisions concerning SSI is a testimony to the complexity of determining how these processes take place and how to develop a valid and reliable model with which to assess them. Despite the fact that in their model of socioscientific reasoning the authors devised a rubric with which to evaluate the degree of sophistication of students' responses in several categories (complexity, perspectives, inquiry, and scepticism), the authors did not subsequently use this model to evaluate how students' responses change after an SSI-based intervention took place. Instead, the authors adapted a pre-existing model (the reflective judgment model). The authors also did not establish any links or parallelisms between the three models; neither did they point out their respective differences.

2.3.2. Research about SSI. Main areas of study

The research about SSI has centred on general aspects, such as those discussed in previous sections, as well as very specific aspects of how students deal with SSI. In his analysis of the literature on the subject up until 2004, Sadler identified four main areas of research of SSI: a) socioscientific argumentation; b) relationships between NOS conceptualisations and SSI decision making; c) the evaluation of information pertaining to SSI; and d) the influence of conceptual understanding on informal reasoning (Sadler, 2004, p. 515). Some of these areas overlap with each other, which is why the classification of studies is not clear-cut. In the following sections some of the more relevant studies on SSI will be discussed.

2.3.2.1. Argumentation and SSI

Driver et al. (2000) have defined argumentation as that human activity where individuals or groups draw conclusions starting from certain premises. In science, argumentation is a commonplace activity by which knowledge is built, since it is used to link data with theory, settle controversies, and discuss the adequacy of experimental set-ups and data analysis, among other uses. Scientists also use their argumentative skills when making public their results in specialised and/or popular journals (Kuhn, 1993; Driver et al., 2000; Osborne et al., 2004).

Given the relevant role of argumentation in, and for, science, many science educators believe that argumentation must be part of scientific literacy. In this context, argumentation would promote students' understanding of scientific knowledge as a socially built enterprise (Driver et al., 2000) and help them to form their own opinions about science-related issues. Osborne et al. (2004) have argued in favour of teaching argumentation skills in the classroom because—besides inviting students to use concepts to build knowledge—it makes explicit their own reasoning processes, enabling teachers to assess it and so improve teaching. Argumentation also requires students to analyse different points of view, assess the evidence, and search consensus (Driver et al., 2000; Zeidler et al., 2003).

SSI offer an excellent opportunity for students to engage in argument (Zeidler et al., 2003), since they invite students to discuss controversial issues of 'science-in-the-making' that scientists are also actively debating (Driver et al., 2000). It has been shown that SSI increase argumentation by students compared with issues dealing only in scientific issues. This may be due in part to the fact that students can conduct an argument on highly interesting topics—using knowledge they have acquired from sources other than school—that involve ethical considerations (Osborne et al., 2004).

Several studies about argumentation in relation to SSI exist, with diverse approaches to the evaluation of arguments that make them difficult to compare. Some assess the structures of arguments, paying no attention to whether evidence or scientific knowledge is used appropriately. Others evaluate the contents of the arguments themselves, without analysing argumentative structures. There are those that focus on the design and evaluation of interventions intended to teach how to conduct an argument and yet others where SSI are taught without an emphasis on argumentative skills. Finally, there are studies that evaluate arguments during the debate of an SSI apart from any specific teaching unit.

In general, the phenomena studied are complex, and the analysis of the structure of arguments by necessity loses much valuable information. This type of study will not be addressed in the present section. A deeper analysis of arguments requires taking into account many more factors, among which are the foundations and knowledge used by students to justify their claims, the distinction between personal opinion and claims supported by the evidence, the use and interpretation of the whole body of evidence, the adequate interpretation of causality relationships, and the consideration of alternative explanations (Sampson and Clark, 2006). Some of the more relevant studies about these issues will be discussed in the following paragraphs.

In his review of the literature, Zeidler (1997) identified five classes of *fallacious thinking* that students commonly resort to when faced with information they have to assess as a means of generating and backing arguments.

The first kind of fallacious thinking has to do with so-called *validity-concerns*. Generally speaking, students recognise that from certain premises logical conclusions can be drawn. However, many students (and adults) commit formal fallacies when drawing conclusions, such as *affirming the consequent* (if P, then Q. Q. Therefore, P; if it rains I will not go out. I did not go out. Therefore, it rained). The analysis of the validity of arguments is further complicated when it involves the beliefs of students. Studies have been conducted that suggest that it is easier for students to extract conclusions if they believe that the premises are true rather than false, even though the validity of the conclusion depends on logic alone. Thus, the analysis of the validity of arguments by students depends both on how well they use logic and on what they personally believe about the topic under consideration (Zeidler, 1997).

Another kind of fallacious thinking results from the fact that students have a ‘naïve conception of argumentation structure’ (p. 488). This means that students do not analyse critically each argument, but rather select those that, for them, have meaning or make sense intuitively. This behaviour leads them to conclusions that seem convincing to them, in light of their personal beliefs. In this case, it is possible for students to hold arguments they do not find convincing ‘in abeyance’, that is, they apparently accept them but without analysing them in-depth or incorporating them into their argumentation process. Thus, these arguments have little or no effect on their original ideas. Discordant data or contradictory evidence are commonly ignored when students derive conclusions from the data (Zeidler, 1997).

Students tend to be very critical of information that contradicts their beliefs, and uncritical of information that supports them. Zeidler has called this kind of fallacious thinking ‘effects of core beliefs on argumentation’ (p. 488). The problem with this kind of flawed analysis is that it implies that, in many cases, the more controversial a claim or topic—or the stronger the beliefs of students—less useful is the analysis of the evidence, which leads to the polarisation of stances and ideas (Zeidler, 1997).

Students also find it difficult to determine how much evidence is sufficient to justify a conclusion (inadequate sampling of evidence). They also fail to consider whether the sample is representative of the population or whether the sampling was adequate. For this reason, students commonly reach hasty or premature generalisations. Since students do poorly at discriminating valid from invalid evidence, on many occasions they rely on their personal experience to justify their claims, overemphasising infrequent events and/or placing undue trust in statistical data (Zeidler, 1997).

Zeidler calls the last kind of fallacious thinking ‘altering representations of argument and evidence’. In this case, students tend to make ‘pragmatic inferences’ to reach their conclusions, that is, they make inferences that go well beyond what the original situation proposes—inferences also heavily imbued with their personal beliefs (Zeidler, 1997).

Fallacious thinking has implications for argumentation, particularly as regards the analysis of information, the drawing of conclusions and, more importantly, the definition of a posture with respect to an issue. The SSI are typical cases in which students face not only scientific evidence, but also interests or beliefs that might affect how they analyse them and which posture they adopt before them.

Other authors focus on the content and quality of arguments given by students. Kortland (1996) used a normative model to evaluate: a) the number of criteria used by students when arguing about a topic; b) the clarity of the arguments; and c) the validity of the arguments. When making a decision about waste management (consuming milk in recycled bottles or in disposable cartons), without prior instruction on the topic, Dutch students of 13-14 years of age used a small number of criteria in their arguments (flavour, consumption behaviour, pollution, recycling, waste), and the validity and clarity of their arguments were of a low quality. After being instructed in the topic and having conducted a debate on it, the validity and clarity of their arguments improved slightly, but the number of criteria used remained poor.

Results suggest that students, in spite of knowledge of the topic at hand, rely on a limited number of criteria when making a decision. Possibly, this limitation in the amount of criteria has something to do with their beliefs about an issue being already deeply rooted—and, thus, impervious to additional or contradictory evidence, as suggested by Zeidler (1997). It is possible that the use of several distinct contexts—with which the student is more or less familiar and, thus, more or less susceptible to the influence of previous beliefs—could help explore if the degree of familiarity or emotional investment that a student has towards a particular issue affects the amount and quality of the criteria used to reach a decision.

Jiménez-Alexaindre and Pereiro-Muñoz (2002) studied whether Spanish students of 16-17 years of age were capable of integrating their theoretical knowledge of ecology with technical data related to a practical problem—i.e., the environmental management of a wetland—to construct coherent arguments and make a decision about the SSI. The assessment of the arguments was based on the offered warrants postulated in Toulmin's model, that is, the reasons given by students to justify their claims. The authors compared the arguments produced by students with those offered—in an interview—by an engineer with expertise in the SSI. The research found that students were able to establish links between their knowledge and the problem and that they used a range of criteria akin to those of an expert. Both the students and the expert used concepts about ecology, environmental impact and technical considerations. A key difference was that students also used many arguments that refer to values.

The results of this study contradict the findings of Kortland (1996), who found that the number of criteria used by students was extremely small. It is noteworthy that, even though students received no previous instruction regarding argumentation, they managed to formulate a variety of arguments. The study shows that it is possible for students to apply what they have learned in class to real problems, provided they are presented with an interesting topic of a suitable level of complexity.

In this case, students—enrolled in a Geology and Biology course—analysed a real case scenario with the capacity to affect the region they live in. It is likely that both the course and the personal stake in the matter favoured deep analysis and consideration together and the use of diverse criteria of assessment of the data. Probably, different contexts would elicit different responses from the same students, since the degree of involvement, personal beliefs, and levels of interest would vary according to the topic.

Walker and Zeidler (2007), for their part, evaluated the contents of students' arguments and the criteria that students used when making a decision. They devised an online teaching unit about genetically modified food (GMF) and promoted debates where the students explained their ideas about the topic. Argurments were classified according to whether the student used information contained in the texts they were provided with, previous personal knowledge or general science content knowledge. The analysis of students' responses showed that most based their arguments on either a mistaken assessment of the evidence or incorrect knowledge. Many of the arguments were themselves not based on facts but on unwarranted assumptions. A third category of arguments comprised personal attacks.

In his study of SSI and intellectual independence, Geddis (1991) worked with a Grade 10 teacher in Canada who, in his classes, used—as an SSI—the origin of acid rain in Ontario as the context for students' debate on the postures defended by different stockholders. After analysing students' responses, the researcher identified three kinds of arguments used by students to explain two of the postures: 1) the stakeholder is wrong; 2) the stakeholder is avoiding the truth of the matter because accepting it would entail a high cost for him or her; and 3) the evidence is never conclusive and stakeholders evaluate it differently depending on what is at stake for them.

Geddis' study emphasises how relevant it is that students evaluate the arguments offered by different stakeholders and determine the probable causes behind these differing viewpoints. This is no easy task and students require assistance from their teacher. Besides, the study brings out the difficulties faced by teachers when they cannot rely on their authority to impose a particular viewpoint. Furthermore, in this study students also reflected on the importance of evidence as a support for claims, even though the author did not expressly emphasise this point.

The study is quite limited because it focused on one group and one topic (acid rain), but offers the opportunity to determine the reasoning processes of students. These processes agree with Zeidler's (1997) conclusion that students find it difficult to understand that several postures can be justified when these are incompatible with students' personal beliefs.

In spite of the diversity of the range of studies presented, it seems clear that argumentative skills are essential for the analysis and resolution of SSI and decision-making. All studies discussed evaluated students' responses to a particular context—scenarios in whose resolution students' beliefs and ideas certainly played a role, influencing how data were assessed, the conclusions reached, and the students' posture towards the issue at hand defined (Zeidler, 1997). For this reason, studies that assess students' responses to a unique situation or scenario and, from it, attempt to deduce how students would respond to SSI in general are necessarily limited in their insights. A study that compares how students respond to different contexts could, in principle, help researchers to understand the influence contexts play in the analysis of evidence and decision-making related to SSI. This in turn could allow determining whether there is a pattern and/or a set of common ideas among responses to a range of contexts.

2.3.2.2. *Evaluation of information and socioscientific issues*

One of the features of SSI is their lack of a unique and correct answer: solving them involves interests and values and, on occasion, even the science that underpins them is controversial. For this reason it is fundamental that students be able to analyse and understand correctly the scientific dimension of the SSI, since it is one of the many factors that help arrive at a justified position regarding SSI (Kolstø et al., 2006). There have been diverse efforts to understand how individuals with no specialised knowledge of science deal with the scientific dimension of everyday problems. In the following paragraphs the most relevant studies in the field are briefly described.

The analysis of SSI by students requires a series of complex skills. Ratcliffe (1996) studied the strategies that students used to assess SSI—individually and in groups. She proposed that, among the skills that students need to develop to solve an SSI, are discriminating between theories and observations and between opinions and evidence; evaluating the validity of evidence; understanding how scientific knowledge is generated; recognising which aspects of an SSI can be addressed using science and where, and how, can information be sought and evaluated; identifying the different agents and values involved in the differing positions on an SSI. Beside this set of skills, a student needs to be able to recognise and assess the risks associated with adopting any of the diverse positions available (Millar and Osborne, 1998).

Many of the strategies mentioned are related to knowledge of the NOS and scientific inquiry skills. Armed with this information, resolution of SSI in school would be much enhanced—at least from the standpoint of their scientific dimension.

Ryder (2001) conducted a review of the literature to determine which knowledge is necessary for a non-scientist to have in order to deal with SSI. He found a great diversity of published papers on the subject, each with a different approach and context. From all these studies he drew categories of elements that individuals used when faced with science scenarios. These categories are:

1) *Subject matter knowledge:* within this category are included knowledge taught at school, knowledge that goes beyond what is specified in curricula—whether because it is too complex or novel— unavailable knowledge, and knowledge that conflicts with what is taught at school.

2) *Collecting and evaluating data:* this category includes the assessment of the quality of the data and the experimental design of research projects.

3) *Interpreting data:* in this category, the author explores the relationship between data and theory—the assessment of the validity of interpretations, the role of theory in the interpretation of data, and the underdetermination of theory by data.

4) *Modelling in science:* this category focuses on the use of models by individuals (even though this use may not be explicit), the assumptions underlying the models, their applicability in different contexts, and modeling errors.

5) *Uncertainty in science:* this category includes the way individuals search for certainty, which are the sources of uncertainty and what are the consequences of it.

6) *Science communication in the public domain:* this category explores how individuals deal with the limits imposed by scientific texts published in the popular media. These restrictions refer to the limited amount of information, especially about methodological aspects and validity of results, the low emphasis on the uncertainty of the data, and the lack of alternative points of view (Ryder, 2001).

This study explores a very diverse set of studies about non-scientists that have to make a decision concerning a science-related issue, whether an SSI or an exclusively scientific scenario. The categories cover a wide range of issues—from those related to school science to more sophisticated epistemological questions. As a result of the approach adopted, Ryder did not take in-depth notice of sociological aspects of science; only in the category where science touches upon the public arena were such concerns included.

Besides Ryder's, other studies exist that specifically evaluate how individuals deal with the scientific dimension of reports of SSI in the popular media that, as previously mentioned, has limitations of its own. The importance of determining how individuals assess this information lies in the fact that the mass media, by their size, influence a large number of people that may, in turn, base their decisions on the information received. That is why it is necessary for people to have adequate conceptual tools to evaluate these kinds of reports (Korpan et al., 1997).

One of the chief aims of scientific literacy is that students be able to analyse texts critically and draw conclusions from them. In order to do this, individuals must use their wealth of beliefs and ideas and subject them to scrutiny, by contrasting them with available information, whether from a text or any learning experience. Phillips and Norris (1999) studied how previous beliefs influence high school students' critical assessment of popular written accounts of science. The authors argued that it is possible for students to follow three critical roads: 1) assess the text critically, using their beliefs and what the text says as the basis for criticism; 2) allow their beliefs to dominate over the data, and thus reach conclusions unwarranted by the text itself; or 3) faithfully adopt what the text says without their beliefs playing a role in the assessment of the text.

These three roads to critical assessment of information complement the conclusions offered by Ryder (2001). They deepen our understanding of how students use their beliefs (of scientific concepts, the NOS, the role and limitations of the mass media) when appraising information presented to them.

Students in Phillips and Norris's study read four popular science reports (concerning the relationship between weather and disease; the discovery of a new animal species; the importance of breakfast and the relationship between milk and diabetes). They were asked for their ideas about each topic before and after reading the text, as well as their personal stance towards the topic of the reports. Only a small minority of students analysed the texts critically, that is, using their previous beliefs to judge the information presented. The majority of students accepted the information provided by the texts without subjecting it to scrutiny; the few students that changed their views after reading the texts did not do so on the basis of a critical assessment of the text, since they failed to mention the reasons or arguments presented by the text and how these influenced their views about it (Phillips and Norris, 1999).

In spite of the fact that the authors do not mention it explicitly in their report, it seems there was some influence of the context, that is, the topic of the reports, on students' responses. The results suggest that the more entrenched students' beliefs are, the less critical they are of the information presented to them.

Studies that attempted to answer the question of how individuals analyse scientific texts have also been conducted. It has been found that a layperson adopts different criteria to assess the trustworthiness of the information presented in an SSI, compared with an expert on the issue. Kolstø et al. (2006) examined the criteria used by science education students to assess the trustworthiness of the scientific dimension of reports of SSI found on the Internet. It is worth keeping in mind that, even though the authors consider the students to be non-experts, the subjects had BA or MA degrees in science and were studying to become science teachers, and so the criteria they use can be very different from what a high school student would use.

The authors classified the criteria used by science education students to assess trustworthiness in several categories and subcategories:

1) *Criteria that evaluate the theoretical and empirical aspects of the information:* Examples of this category are judging the quality of the references that appear on the reports, determining whether conclusions follow from the premises, looking for inconsistencies between the data and the inferences, evaluating the reasonableness of arguments, and checking that the information is compatible with their background knowledge.

2) *Criteria of completeness the data:* Examples of these criteria are the presence of references to the original sources, the presentation of the information with enough detail, and the inclusion of more than one point of view.

3) *Criteria that evaluate social aspects:* These criteria focus on the evaluation of possible competing interests on the part of the author of the report or on the part of

the experts, what are the credentials of the author or experts quoted, whether they are well-regarded within their area of expertise, whether there are controversies among scientists.

4) *Criteria that evaluate the possible use of strategies of manipulation:* These criteria seek to identify when the author of the report resorts to emotional blackmail or sensationalistic claims (Kolstø et al., 2006).

The use of the four criteria above—both in terms of quality and quantity—proved to be very variable among students (Kolstø et al., 2006). One of the limitations of the research resided in not evaluating how well the criteria were applied, that is, whether the knowledge used to judge a report was correct or not. However, the study provides some useful hints for science education. It is striking that many of the students used the criterion of completeness of the data, since judging which information is absent from a text is not an easy ability to develop and is, consequently, absent in many people that tend to analyse the information presented uncritically (Zeidler, 1997).

This study offers the opportunity to understand which are the criteria used by science education students to evaluate the trustworthiness of information. These criteria are diverse and do not always depend on the knowledge of individuals. This suggests that it is possible for individuals to develop criteria for the evaluation of trustworthiness even without being experts in a particular topic. This finding highlights the inadequacy of curricula saturated with facts that will not necessarily prove to be useful in students' life outside school (facts that, worse, constantly change).

The same researcher conducted a study of the criteria of trustworthiness of information in 16-year old students that revealed considerable differences in the evaluation criteria between adults and young people. He used an SSI about the possible link between leukaemia and powerlines in Norway. This is a real issue about which no consensus yet exists among scientists and that directly affects citizens. The researcher found that students used five different strategies to judge whether the information presented to them was trustworthy: 1) detection of problems in the report (disagreement among scientists, interests of scientists); 2) uncritical acceptance of knowledge claims; 3) acceptance of authority with no reasons to accredit trustworthiness; 4) evaluation of knowledge claims; 5) evaluation of authority (Kolstø, 2001).

In this study the author does not clarify whether the acceptance or the evaluation of knowledge claims includes questioning the theoretical foundations, the methods, the analysis of the data, or the validity of the conclusions.

In general, all students trusted the data presented and used limited criteria to evaluate the claims made by the report they had read and analysed. The trustworthiness assessments were influenced by students' position—in favour or against—towards powerlines; furthermore, students did not question the evidence used to justify either the claims or the methods used in the report. The author argues that, possibly, students trust the data blindly because they had studied them previously, in their science classes. One of the most common criteria used by students when judging trustworthiness was the level of disagreement among scientists. The contrast between the data presented—that students accepted as true—and the perceived disagreement among scientists led most students to exhibit a mixture of trust and scepticism towards the information presented, and to fail to question the information more deeply (Kolstø, 2001).

The role of evidence in the evaluation of scientific texts is fundamental, because scientists have a 'core commitment to evidence': ultimately, it is against the real world that theories are tested to see if they work. There are various studies published that probe in depth in the way individuals evaluate evidence when analysing an SSI and make decisions about it.

Ratcliffe (1999) studied the link that students perceive exists between the evidence and the theory when analysing science texts in popular magazines. She compared students of 11-14 years of age against 17-year old students and science graduates (22-35 years). In students' responses to questions about the certainty of the data presented in the reports, they cited elements the researcher divided into the following categories, according to whether they 1) questioned the mechanisms of action of the explained phenomena; 2) evaluated whether the evidence was sufficient to justify conclusions; 3) cited the actual evidence presented; 4) questioned the certainty of the evidence; 5) proposed alternative experiments; 6) analysed the limits of the evidence; 7) showed scepticism; 8) questioned the motivations of scientists; and 9) made reference to the timeliness of the research.

The author found differences between the youngest students, on the one hand, and high school students and graduates, on the other. The main differences were that in older students the role of the personal dimension in the analysis tended to decrease—they cited more evidence. However, the number of different criteria used by younger and older students was similar. The majority of students were capable of distinguishing between established facts and uncertain claims in the reports. The results suggest that younger students have the capacity to understand and evaluate the limits of the evidence and its links with theory—reason enough to merit designing teaching activities aimed at the development of these capabilities (Ratcliffe, 1999).

Another study that investigated how non-scientists related evidence to theory was conducted by Tytler et al. (2001). They used an SSI about burning Recycled Liquid Fuel (solvent waste). The researchers did not work with students, but with three members of the public that participated actively in the controversy, each with competing interests in the issue. All participants were shown evidence obtained from official reports on the case, complemented with criticisms made of the very same reports. When interviewing the participants, the authors distinguished three classes of evidence used to justify their respective positions: 1) scientific evidence (based on the reliability and validity of the data, the validity of the experimental design, and the coherence of the different sets of data obtained); 2) informal evidence (based on common sense, circumstantial evidence, or personal experience); and 3) other issues (environmental, economic, or legal) (Tytler et al., 2001).

Both studies coincide on the assessment of the validity of the evidence by participants; however, in Ratcliffe's (1999) study students also mentioned the scientific knowledge dimension, whereas Tytler's (2001) participants focused on the social implications of the issue. It is possible that these differences are due to the fact that participants in the first study are still in a school context, whereas those from the second group are stakeholders in a controversy.

One of the problems associated with newspapers and magazines being the main source of scientific information for non-scientists is that many of the news stories about science that appear daily in the media are very short and lack enough relevant information to judge the issues accurately and take a position towards them. Korpan et al. (1997) explored what additional information university students asked for to determine if the conclusion of an journalistic short article (fictitious) was plausible. The authors classified the requests for information in nine categories, of which six were clearly related to the search for information: 1) taking into account social factors that play a role in the research; 2) taking into account the theory behind the phenomenon; 3) asking for information about how the research was conducted; 4) asking for data and their statistical analysis; 5) asking information about related research; 6) questioning the relevance of the research.

The authors found that, when students asked for information, the more frequently used categories by students concerned the experimental methods, the social context, the theories behind the phenomenon, and data and its analysis. Few students asked for related research or the relevance of the research. The authors pointed out that the relative frequency of questions about social context was quite low, which seems to indicate that students are not familiarised with the social aspects of science. These results contradict the findings of Kolstø et al. (2006) that suggested that students emphasise social components. These differences could be due to the BA and MA degrees of participants in Kolstø's study—they might be more familiar with the social processes of science.

Previous studies analysed how individuals evaluate information. These individuals had received a traditional education with an emphasis on scientific knowledge but not on the analysis of the data. Is it possible that students can learn to evaluate the data presented in scientific reports? Few studies have addressed the issue of how students' decisions change after they have been taught how to evaluate the quality of the data. Albe (2008) used a teaching unit, that included an SSI about mobile phones and their relationship with health, on adult students (22-34 years of age). In this study, the author promoted the analysis and discussion of contradictory claims about mobile phones and health. Evidence that supported each of the different positions was discussed and students received guidance on how to evaluate the quality of data and the validity of the conclusions. The intervention proved to be successful: at the end of the teaching unit students used the evidence more frequently than at the beginning (Albe, 2008).

As part of the study decisions, and their justifications, about whether students believed that mobile phones are harmful were assessed after the teaching unit had concluded. Albe found that the justifications offered were diverse. In the initial evaluation, the main factors behind decisions were commonsense ideas (or misconceptions) about the effects of radio waves. Values and personal experiences also had considerable influence on the justification of decisions. To a lesser degree, students referred to scientific research and to the lack of conclusive results or convincing arguments. When students were asked what would make them change their minds, the majority claimed that convincing scientific evidence would be needed. Still others mentioned consensus among scientists as a requirement for change. After the teaching unit had concluded, students relied less on commonsense ideas about radio waves and made fewer references to their personal experience. However, they barely used scientific knowledge to justify their positions. At the end of the unit students also mentioned more frequently the role of evidence and social considerations of scientific research (Albe, 2008).

One the most relevant conclusions from the study suggests that being able to interpret correctly the data in a report is not the only skill required by students in order to take a stance towards an SSI. A developed view of the NOS would enrich their decision-making process, for example, in comprehending the origin of scientific controversies and the lack of consensus.

In the studies presented thus far in this section there appear to be contradictory results: some authors found that individuals have the capacity to analyse information in some depth (for example, see Ratcliffe, 1999), while others concluded that the criteria used to evaluate information were poor and superficial (for example, see Kolstø, 2001).

Several of the studies have in common that their authors drew up categories of elements or criteria that non-scientists used to evaluate information related to SSI. Table 4 presents a summary of the categories derived by the authors about which criteria or elements people use when evaluating scientific information given to them. To build the table, Ryder’s (2001) study was used as a basis, since he made a broad review of the literature on the topic and, thus, found a big number of distinct categories. It is worth mentioning that Ryder’s study did not include any of the other studies discussed in this section. These texts focus exclusively on SSI and the analysis of information, whereas Ryder’s had a much broader focus on how individuals deal with scientific information. To these categories were added others proposed by other authors (which explains why some cells are empty).

Table 4 Summary of criteria used by individuals when judging scientific information and popular scientific reports.

Ryder (2001)	Ratcliffe (1999)	Kolstø et al. (2006)	Korpan et al. (1997)	Kolstø (2001)	Tytler (2001)	Albe (2008)
What knowledge of science is relevant for non-scientists?	What elements do children, teenagers and adults use when analysing reports?	What criteria do adults use when evaluating the trustworthiness of a popular scientific report?	What information do students ask for when deciding about short news about science?	What criteria do student use when evaluating the trustworthiness of a popular scientific report?	How do adults involved in a SSI use the evidence?	How do students assess scientific data in SSI?
Subject Matter Knowledge Source: • Part of curriculum • Beyond scope of curriculum • SMK is unavailable • Relevant SMK conflicts with curriculum science	• Theory of mechanism of the research effect	• Compatibility with their own subject matter knowledge	• Agent/theory: Mechanism of action. Scientific knowledge. • The relation with similar works	• Acceptance of knowledge claims • Evaluation of knowledge claims		• Common knowledge (misconceptions included)
Collecting and evaluating data • Assessing the quality of data • Assessing methodology	*Evaluation of evidence presented* • Citing evidence • Proposing alternative experiments • Scepticism showing disbelief in the results		• Design and process of investigation • Design of data analysis		• Reliability of data • Validity of measurement construct • Validity of experimental design • Coherence among different data sets	• Reference to scientific research • Importance of scientific proof
Interpreting data • Assessing the validity of interpretations • Interpretations involves knowledge • Multiple interpretations	*Evaluation of evidence presented* • Limits of evidence	• Logical correctness of argument • Level of expert agreement		• Disagreement among scientists		• Disagreement among scientists

Table 4 (cont). Summary of criteria used by individuals when judging scientific information and popular scientific reports.

Modelling in science • Use of models not made explicit • Assumptions within models • Modelling errors						
Uncertainty in science • Seeking certainty • Sources of uncertainty • Consequences of uncertainty	• Uncertainty of proof					• Uncertainty • Lack of significant results
Science communication in public domain • Incomplete reports • Biased reports	• Scepticism towards media reporting • Motivation of researchers	• Use of references • Completeness of information • Presenting alternative viewpoints • Manipulative strategies				
	• Timing of research		• Relevance			
		Social factors • Author's/researcher's personal interests • Author's/researcher's values • Author's/researcher's competence	*Social factors* • Credentials of researchers • Sponsorships • Peer review	• Acceptance of authority • Evaluation of authority • Bias from researchers	• Matters of trust	• Trust in science • The role of consensus
					Non-scientific • Personal observations • Environmental • Economic • Legal	• Personal considerations

These studies suggest that there are some common features among non-scientists when they evaluate information, as illustrated in Table 4. Among the more commonly used elements to judge information are the use of scientific knowledge, the analysis of the experimental process, and the influence of social factors. It seems clear that for students to be able to face SSI critically, it is necessary to teach them science content as well as epistemological and sociological knowledge—i.e., the NOS.

2.3.2.3. Content knowledge, conceptual understanding and socioscientific issues

In previous sections content knowledge was mentioned as a relevant factor when judging popular reports of SSI. In the constant search—by curriculum designers—for a balance between the quantity of science content and an emphasis on science processes, an awareness of the role that scientific knowledge plays in decision-making is more than necessary (Sadler and Fowler, 2006).

Results from studies conducted thus far are contradictory: some authors have found that scientific knowledge is important for decision-making, whereas others have ascribed to it a secondary role. The studies summarised and discussed in this section are not easily compared—and, consequently, it is not possible to derive a general conclusion—because they use quite different research methods, approaches and SSI. Some centre on the argumentation process and its relationship with scientific knowledge; others on small-group discussions and on students' informal reasoning processes or the criteria with which they evaluate texts containing misconceptions. In this section, studies that explore the role that content knowledge plays in decision-making will be analysed and discussed in more detail.

It is commonly believed that more knowledgeable students—in scientific matters—will construct better arguments. Some researchers argue that this relationship exists, but that it is not a linear one, that is, the ability to construct an argument does not increase proportionally as scientific knowledge builds up; rather, a knowledge threshold is reached from which the quality of argumentation leaps up (Sadler and Donnelly, 2006).

Sadler and Fowler (2006) studied how three groups of students used content knowledge to justify their claims when engaged in argument about an SSI. The researchers compared responses from high-school students, college science majors, and college non-science majors to three different scenarios on genetics. Sadler and Fowler used mixed methods to evaluate the quality of arguments—by means of a rubric—and the role played by the scientific knowledge contained in, or implied by, them—by means of qualitative analysis of the data. Results showed that science majors were the only ones that used scientific content knowledge consistently in their arguments. High-school students and non-science majors exhibited arguments of the same quality. The adequate use of scientific knowledge was the only difference among the three groups, given that, in general, all students justified their claims and arguments in the same way, centring on the social and moral aspects of the issues.

The same research group conducted another similar study, this time with high-school students (15-18 year of age), and obtained similar results regarding the little influence played by content knowledge (on genetics) on the quality of argumentation (Sadler and Donnelly, 2006).

These studies are provocative because they do not attribute great importance to the role of content knowledge—at least school science content knowledge—in argumentation elicited by SSI. Some authors argue that in-depth knowledge of the scientific aspects of an SSI is necessary for a significant leap in argumentative quality to take place (Sadler and Donnelly, 2006). It is likely that different SSI require a different balance between content knowledge and an appreciation of the moral and social values involved. The degree of commitment that students feel towards the issues over which they argue might also be an influencing factor in their responses—hypothetical issues do not affect directly students' lives.

The problem of analysing students' argumentation is that it does not necessarily reflect students' actual informal reasoning, that is, reasoning used by individuals to take a position regarding a controversial topic. An individual with good informal reasoning skills can find it difficult to construct and communicate his or her arguments (Sadler and Zeidler, 2005).

To evaluate the relationship between content knowledge and informal reasoning, Sadler and Zeidler (2005) interviewed undergraduate students in scientific and non-scientific areas, asking them to take a position regarding six scenarios of genetic therapy and cloning. Students also completed a genetics test, the results of which were used to classify them into two groups: adequate or inadequate understanding of genetics. In order to guarantee the assessment of informal reasoning and not argumentation skills, interviews were structured in such a way so as to offer as much guidance as possible to students about how to properly justify their views, think up alternative viewpoints, and offer rebuttals. The authors designed a set of criteria and an a priori rubric with which to assess the quality of students' informal reasoning, such as the presence of reasoning flaws—contradictory claims within a scenario, between scenarios, and the inability to see different viewpoints.

Results showed that there is a significant difference in the number of reasoning flaws among students with a more adequate understanding of genetics and those with a less adequate one. During interviews, students with more knowledge of genetics integrated more data with their arguments, enriching their positions. In spite of the differences in the quality of the arguments, the authors did not find differences in the patterns of reasoning: students used rationalistic, emotive, or intuitive reasoning equally, independent of their level of knowledge of genetics. The authors argued that content knowledge, at least in the case of the SSI they used for research purposes, does have an influence over the quality of students' reasoning—reasoning is context-dependent. Likewise, they advocate the use of SSI as instruments to awaken the interest of students on scientific issues, in order to improve their understanding of the scientific concepts needed to deal with an issue and adopt a position towards it (Sadler and Zeidler, 2005).

Solomon (1992) studied how 17-year old students used their knowledge to discuss, in small groups, scientific issues seen on television—from where people get most of their information. The approach adopted is interesting in itself because it involved social interaction and a focus on citizenship, just what an SSI would entail in real life. Participants in the study were students enrolled in a Science, Technology, and Society course. Among the more relevant results was that students needed at least a modicum of familiarity with scientific content in order to build a proper, significant argument and adopt a position. Likewise, it was found that students' opinions before and after the course changed, but not according to a specific pattern.

The fact that students need to have at least some familiarity with scientific content knowledge in order to start discussing SSI is an argument in favour of teaching content knowledge in school. When students are not familiar with the scientific issues related to an SSI they tend to adopt a negative or precautionary attitude towards science, as evidenced by the statement mentioned by one of the participating students: 'They try to blind you with science' (Solomon, 1992, p. 433). This attitude suggests that there is certain mistrust or fear in students towards science they are unfamiliar with. These kinds of situations, besides being addressed by science teaching, could be minimised if students understood better the processes of scientific activity.

Another study that explored the use of knowledge and decision-making in small group discussions was conducted by Hogan (2002). She used an environmental topic: the control of an invasive aquatic species. Environmental topics are especially relevant as SSI because many of them, such as recycling or energy saving, affect or concern individuals, who sometimes find themselves forced to make decisions about them. The aim of the research was studying how small groups of eighth grade students (13-14 years of age), armed with basic knowledge of ecology, used their knowledge when examining and discussing ecological and economic information about an SSI in order to make a decision. The processes of decision-making in students were then compared with those of an expert in ecology and with the guidelines that scientific organisations have published for decision-making pertaining to environmental problems.

Results from the study show that students individually generated a healthy diversity of justifications for their decisions, and together came up with a set of reasons similar to that proposed by scientists. However, within discussion groups the criteria students came up with were more limited, and there was also much variation among groups. Some integrated their ecological and economic knowledge in a way that reflected the complexity of the problem, whereas other groups centred only on values, personal preferences, or the uncertainty of the available information. The groups that made a better analysis of the issue were those that had a better understanding of basic concepts of ecology, which allowed them to evaluate the information and then construct better arguments and adopt a more complex position. These groups were also capable of transferring their basic knowledge to an unfamiliar situation. This outcome is encouraging in terms of the amount of content in curricula—in a way, this finding justifies SSI presence in science classrooms. The author further argued that, in order to strengthen the decision-making process about environmental SSI, schooling that takes into account 'systems thinking abilities' is needed (p. 364)—the study of the complex interrelations that exist between the parts of a system (Hogan, 2002).

In other studies, criteria used by experts have also been used as a benchmark against which to compare students' arguments. It is of interest for science educators to know on what experts base their opinions, because they can use both specialised knowledge—inaccessible to students—and knowledge included in curricula. In this last case, the difficulty for students lay in being able to transfer knowledge acquired in the classroom to novel situations. Being aware of the necessary knowledge for students to make an informed decision about important issues can help in the design of syllabi and classroom activities.

Grace and Ratcliffe (2002) compared the views of experts in environmental preservation, science teachers, and 15- to 16-year old students on the issue of preservation of the environment. In this case, students were given a framework to guide them in making decisions. In this framework, students were asked to weigh different alternatives and come up with pros and cons, make a decision, and finally review the process through which they had reached the decision. Experts used a wider range of concepts, compared with students, as criteria for making a decision. From these concepts, the most important for science teachers were those related to 'ecology concepts' (p. 1167) and not those related to 'genetics concepts'. This prioritisation of concepts was reflected in the way in which they teach the topic of conservation, but it is also a result of syllabi that push to the background concepts of genetics. The results show that students, apart from scientific concepts, also used values as support for their decisions. The values used depended on the context they were dealing with. The authors argued that preservation issues are taught in school as value-independent situations, even though values are essential for decision-making.

In the three previous studies, it is notable that teenagers can participate in informed discussions about SSI armed with basic knowledge about scientific topics, without needing to know the specific details of the issue in depth, and transfer their knowledge from one situation to a novel one. However, it is also evident in the results that greater knowledge leads to a better analysis of the situation.

A case where the importance of scientific knowledge was convincingly demonstrated was the critical evaluation, by teenagers, of common myths around HIV and Aids. The myths that were evaluated were that HIV can be avoided after practicing unprotected sex by losing great amounts of fluids (sweat and urine) and that having another STD stops HIV infection. In order to determine the trustworthiness of an HIV myth, students have to be able to transfer their theoretical knowledge about the virus to a new situation. Results show that students with a deeper knowledge of HIV rejected more frequently myths about HIV. Also, the reasoning processes through which they evaluated the myths were different from those of students with only superficial knowledge. Students with deeper knowledge used explanations at the cellular level to reject the myths. It is noteworthy that scientific knowledge was not the only kind of knowledge that was cited in relation to the myths. Personal experience, mass media, and common sense also played a role in the arguments and explanations of all students (Keselman et al., 2004).

Generally speaking, results suggest that students can participate in discussions about SSI even with little scientific knowledge of the matter. However, having a basic knowledge of the scientific concepts involved improves their discussion and argumentation processes. Students, at least when engaged in small group discussion, are capable of using a wide range of criteria to justify their decisions, although less numerous and less sophisticated than those of experts. The fact that no clear relationship between argumentation skills and scientific knowledge of students could be established indicates that these skills can, or need to, be developed independently from scientific knowledge, and that other factors are involved in argumentation, besides content knowledge. In students’ responses, values are constantly mentioned.

Knowledge of scientific concepts and the values involved vary significantly among the contexts presented to students and influence their decision-making process. That is why the need remains to compare students' responses when facing different situations of which they know more or less and in which they are more or less involved—in these situations, the degree of involvement of values and beliefs about the issue are bound to change.

2.3.2.4. Nature of science conceptualisations and socioscientific issues

Controversies surrounding SSI have two main sources. The first kind of controversy arises when well-established science is applied in a new social context (for example, the use of an old pesticide against a new pest). In this case, the science-context interaction leads to unforeseen economic, social, and ethical consequences. These SSI are often solved by weighing costs and analysing the risk/benefit ratio, taking into account various social factors. These issues do not generally require, for their resolution, a detailed analysis of scientific evidence, although they do call for an assessment of the applicability (or lack thereof) of the scientific model to the specific situation at hand. The second kind of controversy arises from the social implications of cutting-edge science (for example, the study of the probable outcomes of global warming). In such issues, besides social and economic factors, scientific arguments play a key role, which is why students need to learn to assess them for dealing with these kinds of SSI (Kolstø, 2001; Ratcliffe and Grace, 2003; Zeidler et al., 2009).

Scientific arguments—such as those whose use is required in the second kind of controversies—do not only span fundamental scientific concepts, but also the awareness, by the citizenship, that science is a human enterprise; of how science works and how scientific knowledge is generated; of when knowledge can be considered valid and reliable, among many other things. In essence, people need to have knowledge about the nature of science (NOS) (Millar, 1997).

There is evidence that, for students to develop their views about the NOS, it needs to be explicitly taught in science classes, together with examples and activities that foster the analysis of their views about science (Khishfe and Lederman, 2006). In order to provide guidelines for the explicit teaching of how science works, Kolstø

(2001) suggested a series of tools to help students deal with the scientific dimension of SSI. His proposal was not derived empirically from evidence of how students assess and solve this particular dimension of SSI. Rather, it is the product of a normative model of the author's devising. Kolstø argues that the model should be useful to deal with SSI and that these conceptual tools can help guide the design of science curricula that emphasise decision-making.

Kolstø (2001) suggested that these tools represent the minimum amount of knowledge that an individual has to have in order to deal with the scientific dimension of SSI—so-called 'content-transcendent topics'. Analysis of these topics reveals that they incorporate both aspects of the NOS (i.e., recognising the role and importance of consensus, the place science occupies in society and culture at large, the scope of scientific models, the role of evidence and the notion of 'suspension of belief') and scientific inquiry skills (i.e., distinguishing fact from opinion, requesting evidence and assessing it, questioning the provenance of the evidence, acknowledging the authority and competing interests of the many sources of information available). The rationale behind this set of knowledge and skills is that through its use, students will be able to manage the in-depth analysis of scientific arguments included as part of a SSI, improving their decision-making. It bears remembering that scientific arguments constitute only one part of SSI, which is why understanding the scientific part in-depth is no guarantee of making a sound decision.

In the following paragraphs, each one of these conceptual tools, and their usefulness for decision-making, will be described briefly.

- *'Science-in-the making' and the role of consensus in science:* This conceptual tool is intended to help students understand the rationale behind disagreements among scientists regarding novel research topics. Students should be aware of the difference between cutting-edge science (science-in-the-making)—in which debates and disagreement abound—and well-established science—in which scientists have already reached a consensus. Consensus is reached by scrutinising and exercising criticism, argument and peer-review, that is, through social interaction. Being aware of this social process will allow students to judge many of the scientific disagreements regarding SSI, so as not to attribute them a priori to other causes, such as incompetence or personal interest. Understanding the origin of many scientific disagreements bolsters students' confidence in science. It also fosters an appreciation that, sometimes, decisions need to be made even though the scientific evidence available is not enough to reach a conclusive answer (Kolstø, 2001).

- *Science as one of several domains:* As has been previously mentioned, SSI are complex issues that not only involve scientific aspects, but social, economic, and religious ones as well. In many cases it is almost impossible to say whether some aspects have a bigger role than others, since each one is upheld by different values. Students need to be aware of this fact and, consequently, be able to identify which questions science can answer and which ones it is not suited to answer. Acknowledging that SSI consist of a variety of aspects broadens the scope of the decision-maker.

- *Descriptive and normative statements:* It is important that students distinguish when a claim is fact-like (that is, relatively free from values or interests) and when it is an opinion (that is, a claim guided by implicit values). This skill is a prerequisite for evaluating arguments when forced to make a decision.

- *Demands for underpinning evidence:* When an SSI involves science-in-the-making, in which there is still no consensus among scientists, evidence is highly susceptible to the influence of external interests. That is why students should analyse the evidence used to support a given claim. Finding out the interests involved can help students to understand other viewpoints as well as make a decision.

- *Scientific models as context-bound:* Some scientific models are broad generalisations that can be applied in various contexts. However, in the real world there are external circumstances, ignored by the model, which could affect the behaviour the model predicts. That is the risk scientists run when a model is applied in a different context or situation from the one it was originally intended for. Understanding this helps students to accept that questioning the relevance or the applicability of scientific arguments is perfectly acceptable. However, this does not mean that science is irrelevant—or does not play a role—in solving SSI.

- *Scientific evidence:* Students should be aware of which criteria data have to fulfil in order to be accepted as evidence, that is, evidence that is 'public, intersubjective, and open to validation' (p.302). In many cases, data also need to have statistical validity. The fact that evidence possessing these properties is preferred by scientists does not mean that anecdotal evidence is itself irrelevant for the resolution of SSI—this kind of data can be the starting point for future research. It is important that students recognise the difference between both kinds of evidence.

- *'Suspension of Belief'*: This term refers to the fact that scientists do not make available to the public their conclusions until they have enough evidence to back them up. This is a normative practice and not always takes place, but an awareness of its existence helps students to make decisions because in some cases the unavailability of sound conclusions can be wrongly attributed to personal interests of scientists. Instead, the decision-maker ought to assess the scientific information at hand as the best available at the moment and susceptible to change and improve. Suspension of belief also strengthens the notion that not all decisions can be made with absolute certainty.

- *Scrutinise science-related knowledge claims*: Many researchers believe that the lay public is incapable—due to its inherent difficulty—of assessing the validity and relevance of scientific evidence (for an example, see Shamos, 1995). Nevertheless, Kolstø has suggested that, alternatively, the lay public can pose 'epistemological questions' that denote an understanding of how science works. These questions can refer to the quality of the evidence (for example, how was the evidence arrived at? Does it warrant the conclusion inferred from it?), the source of the evidence, the interests that might influence the source, and its competence in the area of expertise. The lay public might also ask whether there is consensus among scientists on the issue at hand. These kinds of questions can guide students in the assessment, for instance, of information seen, read, or heard in the mass media, as well as helping to distinguish between science and pseudoscience (Kolstø, 2001).

The limitation of this model for solving SSI is that it only takes into account the scientific dimension of the SSI. As previously mentioned, SSI comprise many dimensions—social, political, economic, environmental, etcetera. A single framework that focuses exclusively on what students know about science will necessarily fail to capture the range of ideas that come into play when students face an SSI. The model also ignores the role played by scientific knowledge pertinent to the SSI, a prerequisite for dealing with the scientific dimension of the many-faceted SSI (Grace and Ratcliffe, 2002; Keselman et al., 2004; Sadler and Zeidler, 2005).

This scientific dimension is quite helpful because it allows one to consider, in detail, the various scientific aspects, knowledge, and skills involved in solving an SSI, both for the assessment of students' reasoning and for the design of courses and curricula. In fact, these eight conceptual tools have already been used in studies where courses based on SSI were designed. The results of these studies have been, on the whole, favourable: students have shown sophisticated views and complex reasoning processes, compared with students undergoing a more traditional course (Zeidler et al., 2009).

The name itself of 'content-transcendent topics' suggests that these topics can be usefully applied in a variety of contexts, irrespective of which SSI is under discussion. However, the usefulness of these topics in decision-making remains unproven in practice. Likewise, it is still unknown whether students apply them consistently in a variety of settings and SSI and whether some of these tools are more useful in some contexts than others.

Given the great emphasis that has been placed on scientific literacy—a notion that comprises, among other things, views of the NOS, scientific inquiry skills, and the decision-making regarding SSI—in current science curricula, it is necessary to determine whether an adequate understanding of the NOS actually contributes to the resolution of SSI (Walker and Zeidler, 2007). If one looks at the aspects involved in the resolution of SSI, it would be sensible to conclude that students with a working knowledge of the epistemology and the sociology of science are better equipped to assess and use scientific knowledge, themselves tools in the resolution of SSI (Sadler et al., 2002). As matter of fact, it has been proposed that a better understanding of how science works will allow citizens to 'recognise pseudoscientific claims, distinguish good science from bad, and apply scientific knowledge to their everyday lives' (Bell and Lederman, 2003, p. 353).

However, there is evidence that indicates that, in many cases, knowledge of and about science does not play a predominant role in decision-making, but that other factors—such as ethics, social and political considerations, or personal beliefs, among others—actually guide decision-making. For instance, Fleming found out that adolescents tend to focus on social aspects of SSI; when they actually include in their analysis of the SSI scientific aspects, these tend to be naïve, such as the belief that scientists discover the truth (Fleming, 1986; Fleming, 1986; cited in Bell and Lederman, 2003).

To date, few studies have explored the relationship between the views of the NOS and SSI. In the following paragraphs those studies that have addressed this relationship will be discussed. Available studies can be grouped in three broad thematic areas, according to whether 1) views of the NOS influence how students assess evidence, 2) teaching based on SSI helps to improve views of the NOS, and 3) students use their views of the NOS when making decisions concerning SSI.

1) Do views of the NOS influence the way in which students assess scientific evidence?

One characteristic of SSI is that they present to the student scientific arguments. The use of evidence is part of these arguments. Several studies have been conducted to determine the skills of students to assess evidence within SSI (for example see Kolstø et al., 2006). The particular focus of these studies about SSI and the role of evidence is on how students' views of the NOS relate to the way they assess scientific evidence, especially evidence that contradicts their beliefs.

Sadler et al. (2002) investigated the relationships between views of the NOS and the assessment of the evidence included as part of SSI in students taking a second-year high-school biology class. In order to elicit students' views of the NOS within the context of an SSI, the researchers drafted two parallel reports with similar data but conflicting conclusions about global warming, followed by an open-response questionnaire. Students read both reports and answered the questions; some were even interviewed. Specifically, the questions focused on three aspects of science: a) its empirical basis; b) the fact that it is immersed in a social context; and c) its tentativeness.

With respect to the empirical basis of science, the results of the research showed that almost one-fifth of students were unable to identify experimental data and one-third found it difficult to describe or interpret them. The authors comment that many students confused opinions with data. This finding is important because even though the teacher made constant reference to 'the data' during the class, many students still proved unable to grasp the meaning of this term. When the authors analysed the texts to determine if students considered science as part of a broader social context, the majority of answers expressed the view that economic factors and personal perspectives are relevant to socioscientific debates. Some students made reference to causal relationships between science and society—society causes some problems that have something to do with science, or conversely, that society is affected by the application of scientific knowledge. A few students considered science to be completely isolated from society's influence. In order to determine students' views of the tentativeness of science, they were asked to explain why different groups of scientists can reach contradicting conclusions. Students provided a wealth of reasons with which to explain the different conclusions. These reasons were grouped in three categories: a) scientists had different data or analysed the data differently; b) the interests, beliefs, and opinions of scientists influenced their respective conclusions; c) the differing objectives of each group of scientists determine different approaches to the data (Sadler et al., 2002; Sadler et al., 2004).

An interesting finding was that students—having read the two contradictory reports—did not always consider more persuasive the one that—for them—had more scientific merit. In general, they thought more persuasive the one that agreed with their personal beliefs and their experience. The latter was attributed to the fact that many students tend to keep separate their personal beliefs from scientific knowledge, and any piece of scientific evidence that goes against their beliefs is not seen as valid [this is what the authors termed a quasi-reflective stage in the reflective judgment model by the authors (Zeidler et al., 2009)] (Sadler et al., 2002; Sadler et al., 2004). A subtle difference the authors failed to make regarding the thinking implied by this quasi-reflective stage is that, even though recognising that science has an empirical basis is part of the views of the NOS, the skill needed to differentiate opinion from data is, more than an aspect of the NOS, a skill that belongs to the set of scientific inquiry skills.

It is worth noticing that within the tools proposed by Kolstø (2001) to deal with the scientific dimension of SSI there are some that could contribute to solving problems identified in students.

Besides the study mentioned above, more research has been conducted about how students deal with evidence that goes against their beliefs and what the relationship is of this attitude to the NOS (Walker et al., 2000; Zeidler et al., 2002). Studies have shown that, when dealing with this situation, people react differently. For example, they can ignore the evidence, reject it, question its validity, deem it irrelevant, interpret it in a manner that fits their previous ideas, accept it but not use it to make decisions, enact small changes in their way of thinking or change their framework (Chinn and Brewer, 1998).

In their research, Zeidler et al. (2002) investigated this phenomenon using a sample of 248 college and high school students that completed an open-ended questionnaire that probed their views about the NOS as well as their views about a SSI (specifically, scientific research involving animals). After analysing the responses, the authors grouped the students in 41 pairs—of the same grade level—where each member held a different and opposing view about animal testing. Each pair discussed the arguments both for and against this particular SSI. Afterwards, each member was given a fictitious report containing evidence that contradicted his or her personal views about the issue. Each participant then completed again the same questionnaire about the SSI.

The analysis of responses produced some examples of how views about the NOS influence the way students assess and weigh evidence that goes against their personal beliefs. For instance, one female student believed that scientific evidence was just an opinion. She thus argued that the data contained in the report were irrelevant and that testing on animals needed to be done because it is beneficial to humankind. Another student suggested that scientists do not disclose all the information they actually have because of personal interest. The majority of students accepted implicitly that science is embedded in a social context, since they explained contradicting evidence as resulting from external interests held by scientists. In general, students did not think that contradictory scientific evidence constitutes a good enough argument with which to convince others, since people tend to give priority to their personal beliefs when making a decision. In spite of how strongly personal beliefs can be entrenched, some students did change their views in the post-test. According to the authors, high school students were more likely to change their views because they granted more credibility to arguments espoused by an authority figure.

This study has important implications for the teaching of science using the SSI approach. For starters, teachers have to be aware of the role that students accord scientific evidence and work with them towards enhancing their learning of how to distinguish and assess it. The fact that students discuss with someone with a conflicting stance helps them to consciously analyse their own beliefs, something that will improve their critical skills, apart from fostering a communal building of knowledge (Zeidler et al., 2002).

One of the limitations of this study is the use of a single SSI, since the context influences how students engage with dilemmas. If the context provokes a strong emotional response in the student, he or she is more likely to ignore contradicting evidence and let his or her reasoning be more emotionally-dictated (Zeidler et al., 2002; Sadler and Zeidler, 2005).

Previous studies have shown that responses to SSI and views of the NOS are interrelated, and that presenting students with conflicting evidence or with evidence that contradicts their personal beliefs can elicit their views about the NOS. The fact that students use, to a greater or lesser extent, their views of the NOS when engaging with SSI suggests dealing with this issues in the classroom could help improve students' views of the NOS.

2) Does science teaching based on SSI help improve students' views of the NOS?

Khishfe and Lederman (2006) investigated the effect of explicit teaching of the NOS on an SSI (global warming). The authors were interested in finding out whether it is more effective to teach the NOS in an integrated approach together with an SSI or in a non-integrated way. In the first case, the activities chosen for the teaching of the NOS involved issues related to global warming embedded in the lessons. In the second case, the chosen activities for the teaching of the NOS had nothing to do with global warming but still were embedded in the lesson about this topic. In both cases, the integrated and the non-integrated approaches, the teaching of the NOS was explicit since it has been demonstrated that students do not improve their views of the NOS when studying science or participating in research activities where the NOS is not made explicit. The rationale behind comparing the integrated approach against the non-integrated was that maybe students would improve more their views about the NOS if these were taught within an engaging SSI.

A total of 42 ninth-grade students (between 14 and 15 years of age) participated in the study. They were grouped in two classes taught by the same teacher trained in the teaching of the NOS. One of the classes received the integrated approach; the other the non-integrated one. Students completed open-ended pre- and post-tests and were interviewed before the beginning and after the end of the six-week teaching unit. Five aspects of the NOS were covered in the unit: the tentativeness of scientific knowledge, its empirical base, the role of imagination and creativity in the construction of knowledge, the distinction between observations and inferences, and the subjective nature of knowledge.

The results show that students from both groups improved their views of the NOS in the five aspects considered. However, no significant differences between the integrated and the non-integrated approach were found. The authors argue that this does not mean that the NOS should be taught isolated from science content—the context chosen to teach the NOS can greatly influence the change of students' views (Khishfe and Lederman, 2006).

These results suggest that science teaching using SSI helps students to improve their views of the NOS (as long as these are made explicit during the course), at least as well as the non-integrated with SSI teaching of the NOS. The limitation of this study lies in its reliance on a single SSI for the six-week course—it is possible that a course that incorporates several SSI would be able to reinforce more sophisticated views of the NOS in students, given that they would have the chance to apply their views to a variety of contexts.

3) Do people use their views of the NOS when making decisions about SSI?

Even though interventions where views of the NOS are taught explicitly improve to a greater or lesser degree the views of students (Khishfe and Lederman, 2006), this improvement in no way guarantees that students will be able to transfer their knowledge to different contexts and use it to make informed decisions.

In order to investigate to what extent students resort to their knowledge of the NOS when making a decision, Walker and Zeidler (2007) designed a 10.5 hour web-based curricular unit. A total of 36 students—from grades 9 to 12—reflected upon the issue of genetically-modified foods (GMF). Throughout the unit, students discussed with their teacher and amongst themselves and answered explicit questions about the NOS in relation to GMF. Most students exhibited relatively sophisticated ideas about the tentativeness and certainty of scientific claims and about subjectivity, imagination and creativity in science. However—surprisingly, given the emphasis of the unit—in the debate at the end of the curricular unit students failed to incorporate into their arguments ideas about the NOS that had been explicitly discussed previously; rather, students used other kinds of non-scientific arguments. When they resorted to the evidence, they did so in a superficial manner and ended up constructing a considerable number of fallacious arguments.

The authors accept that decision-making about SSI involves several additional factors to scientific and epistemological ones. However, they emphasise the relevance of these kinds of knowledge for the assessment of scientific claims, themselves a key aspect of solving these dilemmas. The authors go on to suggest that better scientific knowledge about the specific topics involved in an SSI can help in decision-making and that teachers should teach explicitly to students how to apply ideas about the NOS when making a decision. It remains a possibility that, as in previous studies, the choice of the SSI influenced how and when students rely on their views of the NOS in decision-making, but the present study only addresses one SSI and, as such, might not detect these subtle differences.

The value of this study lies in that—apart from investigating if students improve their views of the NOS after instruction—it assesses whether this kind of knowledge is used in decision-making about SSI. It is worth considering that one of the reasons for including aspects of the NOS as part of scientific literacy lies in the positive role they can play in students' thinking when facing a decision about science-related issues. If this objective is left unfulfilled, it is necessary to reassess how the NOS is taught, so that it can be taught in a way that is applicable to SSI.

Bell and Lederman (2003) also studied the role of the views of the NOS in decision-making about SSI. Their sample comprised adult participants, and in this sense differs from the rest of the studies discussed so far. Bell and Lederman selected professors—both scientists and non-scientists—from several universities, of a similar qualification level. The participants were divided in two groups, according to whether or not they had sophisticated views of the NOS. The majority of professors that worked in scientifically-related matters exhibited more sophisticated views about the NOS than those professors that did not work in a scientific field. All participants completed a decision-making questionnaire consisting of four controversial scientific scenarios (foetal tissue implantation, global warming, the relationship between diet and cancer, and the relationship between cigarette smoking and cancer) and a set of 3 to 5 questions per scenario. An important difference among scenarios was the degree of emotional involvement required of respondents.

The majority of the decisions made about different scenarios by both groups of people—those with sophisticated views of the NOS and those without—were similar. The authors analysed the responses to determine whether, in spite of having made the same decision, the reasoning, or the factors taken into account, behind the decision differed. They found a total of 16 factors that professors took into account before making a decision, which were then grouped in 8 categories, namely: moral/ethical issues, social/political issues, support of science, pragmatism, NOS, personal issues/values, personal philosophy, economics (cost/benefit). The authors point out that they found no significant differences in the set of factors used by both groups and that references to aspects of the NOS were scarce and, for the most part, touched upon the notion of scientific evidence only superficially. With regard to the reasoning behind the decisions, five strategies were identified: weighing the evidence, maintenance of the status quo, risk/benefit analysis, cost/benefit analysis, and decisions based on values. The only observed difference in the reasoning between groups centred on the nature of evidence—the group with the more sophisticated views of the NOS saw evidence as fallible but useful, whereas the other group saw it as true and immutable. Nevertheless, this difference had no influence in the decisions made by the participants (Bell and Lederman, 2003).

The results of this study emphasise the important role of factors such as values or practical issues play in decision-making concerning SSI. Just as in Walker and Zeidler's (2007) study previously mentioned, decision-makers did not use their knowledge of how science works in the decision-making process. In Bell and Lederman's (2003) study, different scenarios, with which respondents felt more or less involved, were used as a means of analysing how the context influences the use of ideas about the NOS—and other factors—in decision-making concerning SSI. However, the authors attempt no detailed analysis of the influence of the context in the use of different reasons for making a decision, rather focusing on the differences—or lack thereof—between the groups analysed. Analysis of the factors used by participants reveals that in one scenario (foetal tissue implantation), no respondent considered an aspect of the NOS as a determining factor, whereas in the rest of the scenarios some of the respondents did consider the NOS as a factor to a bigger or lesser degree. Even though the authors make no mention of it, this difference speaks of the influence contexts have on the consideration of factors for decision-making about SSI, event though there is no study so far that compares different contexts.

In conclusion, it was observed that the views of the NOS influence the way in which students evaluate evidence because they recognise that science is part of society, its knowledge is tentative and presupposes a measure of creativity. Furthermore, it was seen that an SSI-based education has a positive effect on students' views of the NOS. However, when making a decision, the views of the NOS are not taken into account or do not influence the decision itself. The latter may be due to the relative weight ascribed to other factors considered before making the decision (for example, values or practical aspects) or to individuals' lack of understanding of the importance the scientific dimension has in the resolution of SSI. It is possible that a science education that makes explicit use of the NOS in decision-making can help students value and use these kinds of knowledge, even though there are no studies in this area. Also, it is not known whether students value and use more or less some aspects of the NOS to solve some SSI and not others.

2.4. Science education and pseudoscience

Pseudoscience has been defined as 'claims presented so that they appear [to be] scientific even though they lack supporting evidence and plausibility' (Shermer, 1997, p. 33, cited in 2002). In the literature on the topic, certain demarcation criteria have been established to distinguish science from pseudoscience. Radner and Radner (1982) proposed that the criteria with which to distinguish one from the other must be based on their 'ways of operating': those of pseudoscience are alien to proper science. As markers of pseudoscience they propose the following:

- *Anachronistic thinking:* many pseudoscientific ideas are actually a return to archaic visions of the world and the way things were believed to work.

- *Looking for mysteries:* promoters of pseudoscientific ideas attempt to pass them as scientific anomalies, and generally adopt ideas well outside the scientific framework with which to explain these anomalies.
- *Appeal to myths:* Some pseudoscientific ideas have their origin in ancient myths and legends.
- *The grab-bag approach to evidence:* Individuals that support pseudoscientific ideas believe that a great amount of evidence (for instance, the number of UFO sightings or of kidnapped people by so-called aliens) is more convincing than its quality.
- *Irrefutable hypotheses:* If hypotheses cannot be refuted, they will never be proven wrong, even though the ideas they embody do not reveal anything about the world.
- *Argument from spurious similarity:* Some pseudoscientific ideas are presented as viable ones because their proponents argue that they are based on legitimate science.
- *Explanation by scenario:* Many pseudoscientific ideas are not generalisable.
- *Research by exegesis:* In science, literary interpretation has no place; however, in pseudoscience (as in art and religion) this kind of interpretation is commonplace. Besides, any argument that seems to support the point of view of a pseudoscientific idea receives great merit, independently of its quality.
- *Refusal to revise in the light of criticism:* Many of those who support pseudoscience draw confidence from the fact that their ideas have never been proven wrong (contrary to what happens to many scientific ideas that are always susceptible to change). There are various ways to avoid criticism, for example, make empty or imprecise arguments. Criticism never forces changes on pseudoscientific ideas.

On the other hand, Lilienfeld et al. (2001) summarised the diverse criteria, cited in the literature, that characterise pseudoscience:

Table 5 Features of pseudoscientific claims (from Lilienfeld et al., 2001, p. 182)

- Unfalsifiability
- Absence of self-correction
- Overuse of ad hoc immunising tactics designed to protect theories from refutation
- Absence of 'connectivity' with other domains of knowledge (i.e., failure to build on extant scientific constructs)
- The placing of the burden of proof on critics rather than on the proponents of claims
- The use of obscurantist language (i.e., language that seems to have as its primary function to confuse rather than clarify)
- Overreliance on anecdotes and testimonials at the expense of systematic evidence

Not all pseudoscientific claims have the features mentioned, but generally they have more than one. Both lists have elements in common, related to the lack of openness to criticism, the lack of support from a wider, well-supported conceptual framework, and the absence of systematic evidence.

If the criteria for identifying pseudoscience are relatively clear-cut, why do so many people still believe in it? Lindeman (1998, p. 258) has suggested that belief in pseudoscience results from the basic need of people to 'comprehend self and the world, to have a sense of control over outcomes, to belong, to find the world benevolent and to maintain one's self-esteem'. The author further argues that science is not capable of covering these needs. On the contrary, science produces a feeling of ignorance about many things in the world, that the world is unfair, indolent before our needs, and chaotic.

Beliefs in pseudoscience are based on what Lindeman calls *experiential thinking* that—contrary to rational thinking—is used to make quick decisions using simple mental operations. This kind of thinking guides our behaviour most of the time and is based on concrete information more than on abstract one that requires much mental processing. One of the main sources of concrete information is personal experience, unconsciously activated in the form of intuitions or 'vibes' that produce a feeling of well-being or unease about a decision. Due to their roots in experience and not in logic, behaviours derived from experiential thinking are persistent and difficult to change (Lindeman, 1998).

Pseudoscientific claims are exceptionally good at appealing to the experience of people and to their needs to understand and control diverse situations. For example, astrological predictions, usually vague and imprecise, confirm the image people have of themselves. Another example of how pseudoscience masks the need to understand and control the world is evident after an unexpected event happens, for which it is not easy to find a rational explanation (such as a illness or an unannounced death). In this case, people, especially those with low tolerance to uncertainty, rely on magical thinking to explain the cause of the event and find its meaning. It is quite common for people in such situations to search for information consistent with their beliefs and ignore or discredit contradictory information (Lindeman, 1998).

In spite of the influential role of experiential thinking on the beliefs and decisions of people, several researchers have claimed that a better understanding of the NOS could help students distinguish between science and pseudoscience (Erduran, 1995; Kolstø, 2001; Bell and Lederman, 2003). When looking at the demarcation criteria between science and pseudoscience, it is reasonable to think that having a clear idea both of fundamental scientific concepts as well as of how science works can prove to be useful for decision-making. The majority of the studies about pseudoscience are based on interventions designed to teach students to distinguish between pseudoscientific topics within a discipline. Unfortunately, in the field of educational research little attention has been dedicated to pseudoscience and its relationship with knowledge of, and about, science.

Several surveys have concluded that a considerable proportion of the population is willing to believe pseudoscientific claims. In the survey conducted by the National Science Board in the United States, more than 25% of people surveyed claimed to believe in astrological predictions and UFOs. More than half believed in extrasensory perception, ghosts, faith healing, and lucky numbers. Surveys also showed that the proportion of people that believed in pseudoscience was increasing (National Science Board, 2002).

The belief in pseudoscience is worrying, especially when it endangers the health and well-being of people. In the same survey mentioned above, 88% of people agreed with the idea that 'there are some good ways of treating sickness that medical science does not recognise.' (National Science Board, 2002, p. 7-38).The number of users of alternative medicine, as well as the amount of money spent in these kinds of treatments, have increased (National Science Board, 2002). Infirm people that submit themselves to alternative treatments can lose valuable time that would be better spent in a proper medical diagnosis and an efficient treatment (Martin, 1994). On the other hand, if the person has received a false diagnosis by a charlatan, he or she will submit to unnecessary treatment that can produce stress, suffering, and unnecessary expense.

Lindeman (1998) explains the tendency to believe in alternative medicine on the grounds that it appeals directly to experiential thinking. Explanations that promoters of alternative treatments provide about the mechanism of action of these are based on concrete concepts and their credibility is based on testimonials (that is, personal experience). Testimonials appeal directly to emotions and awaken empathy and, in many cases, are more efficient than statistical evidence in convincing people. Many treatments promise easy solutions with no side-effects, producing in people a sense of well-being and control over the situation. Besides, these kinds of treatments place a moral value on concepts such as natural (versus synthetic) or toxicity. These kinds of dichotomous claims mix concepts of health/disease with good/bad judgments (in the moral sense), favouring magical thinking in people.

In Mexico, the panorama with respect to pseudoscience is not that different from the one in the United States. A survey on perceptions about science and technology conducted in 2002 showed that a third of respondents believed that parapsychology is 'very scientific', whereas half of respondents believed the same thing about astrology (a similar result to the one obtained in the European Union). The majority of people feel medicine is the 'most scientific' of all sciences (Consejo Nacional de Ciencia y Tecnología, 2002). This last remark can lead people to trust fully in any kind of medical information that sounds scientific.

These results invite the question of whether an improvement of science education can help decrease the prevalence of these beliefs. How science is taught in most schools could be a partial cause of the uncritical attitude people have towards pseudoscience. In general, science classes do not develop critical thinking skills, but rather emphasise the learning of facts. Laboratory activities are designed to guide students to a pre-established answer, without helping them develop their skills to assess evidence critically or develop alternative explanations. The lack of historical and social context in the teaching of science and the elitist and authoritarian attitude of science can also be factors that foster a lack of critical thinking among people (Walker et al., 2002). To worsen things, there are many teachers that believe pseudoscientific claims such as those of astrology and creationism (Rosenthal, 1993; Kallery, 2001).

The present approach to science education contributes little to students' understanding of how science works and which is the role of evidence in the construction of knowledge, which in turn makes it difficult for them to distinguish science from pseudoscience.

To date, there are no conclusive studies that show that science education, as imparted in most classrooms, plays a role in the identification of pseudoscientific issues and in helping students to make better decisions when faced with one. However, there are some studies and surveys that suggest that science education does influence the assessment of some issues. These studies have centred on the relationship that exists between an individual's educational level and the scientific knowledge that they possess (of scientific concepts) with the propensity to accept uncritically pseudoscientific claims.

An example of these kinds of studies is the survey conducted in the United States about healing with magnets. Of interviewees that had not concluded high-school, 18% responded that the topic was not-at-all-scientific, whereas among college graduates 35% chose this response (National Science Board, 2002). This survey, even though showing that more graduate students believe a pseudoscientific claim not to be scientific, is quite discouraging: it implies that 65% of graduate students think that healing with magnets has some science to it.

Another survey, whose purpose was exploring the link between the level of knowledge about scientific concepts of university students and the propensity to believe in pseudoscience, found that having robust scientific knowledge is not enough for people to distrust pseudoscience (Walker et al., 2002). This survey had the telling disadvantage that it comprised only questions about easy to memorise scientific knowledge that required no actual understanding. Questions also failed to probe respondents' understanding of and about science. Furthermore, the scientific concepts researched were not linked to pseudoscientific issues in the survey. However, given the scarcity of studies on the subject, it represents a good starting point for appraising the relationship between education and the propensity to believe in pseudoscience.

To surmount the limitations of the previous survey—specifically about highly specific questions about scientific concepts—Johnson and Pigliucci (2004) added to this survey a set of questions about the NOS. These questions covered topics such as the tentativeness of science, the scientific method, the inferential nature of theory, the role of experiment, theory-ladenness, and the relationship between hypotheses, theories, and laws. Pseudoscientific topics included in the survey were the healing power of magnets, aliens in Area 51, telepathy, astrology, the existence of Big Foot and the Loch Ness monster, luck associated with chain letters, extrasensory perception of animals, voodoo, and bad luck and broken mirrors (Johnson and Pigliucci, 2004).

In this study, the authors compared responses of science majors (mainly from biology) and non-science majors. Just as in Walker's (2002) study, science majors surpassed non-science majors in scientific knowledge. However, no differences were found between scores in both groups for aspects of the NOS. Less than half of the students in each group exhibited sophisticated views of the NOS: the questions on the relationship between laws and theories and those on the role of experiment in science were the ones that received the lowest scores.

Neither were differences in the propensity to believe in pseudoscience observed. In general, the belief in pseudoscientific issues sampled was low, the exceptions being the healing powers of magnets, aliens in Area 51, and clairvoyance (Johnson and

Pigliucci, 2004). The pseudoscientific topics chosen were varied, although it has been reported that there is a high propensity to believe in alternative medicine topics (National Science Board, 2002), as evidenced by the increased positive responses towards healing magnets –the only heath related topic in the survey. These kinds of topics, given their impact on people's lives, merit more research.

It is possible that the absence of differences in the views of the NOS between science and non-science majors results from the way science is taught: emphasising concepts over understanding of the NOS. Unfortunately, in this study it was not possible to compare whether students with more sophisticated views of the NOS are less likely to believe in pseudoscience than students with more naïve views. The question remains of whether students with more sophisticated views of the NOS have better conceptual tools to evaluate critically pseudoscientific claims.

2.5. Summary of the key aspects that informed the present study

Many science educators agree that scientific literacy, in spite of its various approaches, has among its aims the education of citizens capable of making decisions involving science in everyday situations (for example, see Millar and Osborne, 1998; OECD, 2003). There is consensus on what a scientifically literate individual should know, not only about fundamental scientific concepts, but of ideas of the NOS (Driver et al., 1996).

Unfortunately, many students and science teachers do not possess developed views of the NOS (McComas et al., 1998). In order to rectify this problem, diverse strategies to teach the NOS have been tried (Lederman, 2007). It has been shown that an approach that makes explicit the views about science and that promotes that students reflect upon their original ideas can prove to be more successful than an implicit approach to modifying views (Khishfe and Abd-El-Khalick, 2002). However, these views have been difficult to change and, when they have improved, individuals keep having difficulties in transferring them to novel contexts (Abd-El-Khalick, 2001).

On the other hand, the idea that scientific literacy must prepare individuals for making informed decisions has led to research on the processes through which individuals make decisions. The main focus has been on SSI, complex topics where a variety of factors have to be considered for their resolution (Ratcliffe and Grace, 2003).

It has been observed that when resolving an SSI, individuals commonly use several kinds of fallacious thinking, which lead them to make a partial and equivocal assessment of the available information and, thus, to ill-informed choices, especially when their beliefs about the issue are strongly held (Zeidler, 1997; Phillips and Norris, 1999). In general, it has been found that when individuals assess the information they tend to use several criteria—of varying quality and level of depth. Among these criteria are theoretical and empirical aspects involved in the issue, the completeness and validity of the data and the experimental design, whether the evidence warrants the conclusions, social aspects, and the possible use of manipulative strategies (Ratcliffe, 1999; Tytler et al., 2001; Kolstø et al., 2006).

Besides the criteria cited above, it is likely that content knowledge also plays a role in decisions about SSI, even though its role remains uncertain. Some authors claim that it only has an effect when the individual is an expert on the issue (Sadler and Fowler, 2006), whereas other authors have observed that a basic level of knowledge is the only thing that is needed for students to engage with SSI (Solomon et al., 1992).

In spite of the suggestion that views of the NOS contribute to scientific literacy, their role in decision-making remains controversial. It has been found that many students do not distinguish between data and opinion and consider that scientific controversies are due to personal interests of scientists. Even more, the analysis students perform of the validity of the evidence appears to be influenced by their beliefs on the topic (Chinn and Brewer, 1998; Sadler et al., 2002; Zeidler et al., 2002). Even when students have discussed ideas of the NOS previously and possess sophisticated understandings, they do not tend to incorporate them in their arguments in order to make decisions about SSI; rather, they use other non-scientific arguments. When they do resort to the evidence, they tend to it superficially, using frequently fallacious arguments (Bell and Lederman, 2003; Walker and Zeidler, 2007). One limitation of the studies so far is that they have not compared students' responses among different contexts.

It has also been suggested that ideas of the NOS can help individuals to differentiate science from pseudoscience (Kolstø, 2001; Bell and Lederman, 2003). Pseudoscience can have a big effect on people's lives, especially because many people believe that other alternatives unrecognised by science exist capable of curing disease (National Science Board, 2002). Up until now the role of the NOS in decision-making about pseudoscientific issues has not been demonstrated, studies have limited themselves to superficially evaluating the use of ideas of the NOS and the disposition to believe in pseudoscientific ideas. Results show that there appears to be no relationship between both kinds of ideas, although the difficulty of finding individuals with sophisticated understandings of the NOS has represented, and continues to represent, a problem for research in this field (Johnson and Pigliucci, 2004).

Chapter 3. Methods

3.1. Rationale

Enabling students to make informed decisions about science-related issues they face in their daily lives is one of the main objectives of science teaching. Given that the nature of these kinds of issues is complex, both scientific and non-scientific factors need to be taken into account when making a decision about them. It has been suggested that—within the scientific dimension of the dilemmas posed by these issues—knowing about the nature of science (NOS) can contribute to decision-making (Kolstø, 2001; Sadler et al., 2002; Bell and Lederman, 2003). Nevertheless, research so far suggests that people's views of the NOS do not influence, in any significant way, their decision-making processes regarding socioscientific issues (Bell and Lederman, 2003; Walker and Zeidler, 2007).

There is limited evidence in support of the notion that the context—that is, the varied situations an individual can come to face—influences how individuals weigh and consider each factor involved in making a decision (Zeidler et al., 2002; Bell and Lederman, 2003). So far, however, there has been no detailed study of the specific weight the NOS might have in the decision-making process when facing different contexts. The present study aims to determine if there are any differences in how ideas about the NOS are applied when individuals must make a decision about different contexts, and whether or not these ideas have a role in the actual decision. This could be important in the selection of SSI topics for further research and for the design of teaching units involving SSI.

This study explored the differences in the use—for individual decision-making—of views of the NOS in three kinds of contexts: 1) socioscientific issues in which experts have yet to reach consensus and/or there is a lack of evidence; 2) issues in which scientific knowledge is well established; and 3) issues involving pseudoscientific notions. This third kind of context has yet to be considered in the research literature on decision-making and the NOS and, therefore, there is no evidence of which factors are ideas or factors are used by students when deciding about pseudoscientific issues. Some researchers have suggested that a sophisticated understanding of the NOS can help to distinguish pseudoscientific notions from genuine scientific ones (Kolstø, 2001; Bell and Lederman, 2003). So far, it remains to be seen whether an understanding of the NOS can actually help students make decisions about these issues. Pseudoscientific issues are quite similar to SSI—both rely on scientific language (although used without precision in the case of the former), involve decision-making at the individual, social and policy levels, appear in the mass media (with pieces both in favour and against), require a cost/benefit analysis and the assessment of risk, and involve moral and ethical values. Due to their similarity, and also to the possible impact of these issues on daily life, the present study attempted to determine if there are any differences in how students reason from context to context and how they use their ideas about the NOS when dealing with socioscientific and pseudoscientific issues.

On the other hand, it has been well established that the explicit teaching of the NOS improves the views of students about it, even though the positive effect varies and in not all cases is significant (Khishfe and Lederman, 2006). This study determined whether a college course expressly designed to teach a sophisticated view of the NOS does actually improve students' views. Furthermore, whether this course influences the factors or ideas students come to rely on to make decisions about science- or pseudoscience-related matters was determined.

3.2. Research Questions

- What ideas about the NOS do students draw upon when asked to make a decision on a socio-scientific issue, a well-established scientific issue or pseudo-scientific issue?
- What differences exist in the ideas about the NOS that students draw upon when making a decision on controversial socio-scientific issues, well-established scientific issues or pseudo-scientific issues?
- To what extent are students' ideas about the NOS associated with the acceptance or rejection of the option presented?

- To what extent do students' ideas about the NOS change after taking a course focused on the relationships between science and society?
- To what extent do ideas about the NOS that students draw upon when making decisions on socio-scientific issues, well-established scientific issues, and pseudo-scientific issues change at the end of the course?

3.3. The context of the study

The study was conducted in University A, a Mexican public university. Since 2006, the School of Chemistry of this university imparts a 3-hours a week—for a total of 48 hours a term—course called 'Science and Society' to all first-term students. In the term when the study took place, there were 18 'Science and Society' groups, with an average of 65 students per group. Pairs of teachers are tasked with teaching each group—both of them are present at all classes. The subject coordinators have striven to pair teachers with different backgrounds, one trained in the sciences and the other trained in the humanities. This goal is not always accomplished. It is worth mentioning that there is no training program in place for the teaching of this subject and that the criteria behind teacher appointment are not well established—many have MA degrees in Philosophy of Science, while others are full- or part-time chemistry teachers from the School of Chemistry. Thus, not all teachers have the same level of knowledge about the NOS.

The main objective of this course, as stated in the curriculum, is to increase the awareness of undergraduate students about 'the social and human aspects of science and technology, their scope and their impact.' Likewise, students are expected to develop 'a better understanding, a positive attitude, and an increased sensibility towards the cultural, philosophical, social, historical, ethical, and political aspects of science.' Ultimately, students should be 'capable of making informed decisions, based on argumentation, effective communication, critical thinking, and intellectual independence.'

To achieve these objectives, a variety of teaching strategies are used, including debates, readings, research projects, and analysis of media reports, among others.

Likewise, the contents of the subject are varied, and include an introduction to STS topics such as sustainability, water use, energy, and biotechnology. Teachers are not required to cover all topics—the coordinators actually emphasise to teachers that the main issue is to accomplish the above objectives; the suggested topics are to be used as contexts with which to illustrate the various philosophical and sociological aspects of science.

Since there is no standard assessment for this course, each pair of teachers assesses their students differently, either through end-of-term exams or through coursework during the term.

3.4. The Students' Understanding of Science and Scientific Enquiry (SUSSI) questionnaire

3.4.1. Rationale

There are several instruments—both of a qualitative and a quantitative nature—designed to evaluate the views of the NOS of individuals of a variety of age groups. Generally speaking, quantitative instruments have been criticised on the grounds that researchers' interpretations of items—and answers to them—do not agree with those made by students. Furthermore, the design of these instruments allows this fact to pass unnoticed, since it does not allow the researcher to check the agreement between interpretations. Qualitative instruments do not tend to suffer from this problem but, on the other hand, they have the drawback that their administration and interpretation is time consuming. This makes qualitative instruments difficult to use with large samples, and, what is more, students may not have the skills to express themselves properly and eloquently in writing (Liang et al., 2005; Lederman, 2007).

The present study required assessing the views of the NOS of a large sample of college students. For this reason, an instrument capable of combining both quantitative and qualitative—so as to diminish the risk of misinterpretation on the part of the researcher—approaches seemed the ideal choice. Besides, in order to compare students' views among groups and before-and-after the course, it was necessary that results be quantifiable. The instrument selected to assess students' views of the NOS was the 'Student Understanding of Science and Scientific Inquiry' (SUSSI) test (Liang et al., 2008), one that combines qualitative and quantitative approaches and produces quantifiable data.

3.4.2. Description of the instrument

The SUSSI test was designed with adult respondents in mind, and evaluates six aspects of the NOS, namely the: 1) difference between observations and inferences; 2) tentativeness of scientific knowledge; 3) difference between theories and laws; 4) influence of society and culture on science; 5) role of creativity and imagination; 6) scientific method. For each of these aspects of the NOS, the questionnaire includes four Likert-scale items, each representing both informed and naïve views, as well as open questions that ask either for an explanation or an example that illustrates the particular viewpoint of the student (see Appendix A). In total, the questionnaire has 24 Likert-scale items and six open questions.

The questionnaire was validated originally by its authors with a panel of nine experts in the area of the NOS. The items were fine-tuned with responses provided by pre-service teachers, both in writing and orally, through interviews. The questionnaire was afterwards validated in Turkish, Chinese, and English languages by its authors (Liang et al., 2009). To prepare its Spanish version, two researchers, fluent in Spanish, translated independently the English version, compared their respective translations, and discussed any differences in interpretation until a 100 per cent agreement was reached. Furthermore, a pilot study was undertaken, during which students' understanding of the questions was ascertained.

3.4.3. Analysis of the data

Likert-scale items were interpreted by assigning values of 1 to 5 to the answers, 5 being assigned to informed or sophisticated views. Open responses were interpreted through a rubric proposed by the authors of SUSSI that details what the informed view for each aspect of the NOS consists of. A value of 1 was given to naïve views and a value of 3 to informed views. To determine its reliability, Cronbach's alphas were calculated for the full questionnaire and for each subscale (that is, for each heading of the NOS in the questionnaire, each consisting of 4 Likert-scale items).

To determine whether the views of the NOS changed as a result of the ‘Science and Society’ course, a SUSSI questionnaire was administered both in the first weeks of the course and in its final week. Results from both administrations were compared using a dependent *t*-test and the effect size for each heading was determined. Likewise, the differences between both participating groups were compared using an independent *t*-test.

3.5. The Decision-Making Questionnaire

3.5.1. Background

Several studies about SSI use as probes scenarios that present a controversial issue about which students have to make decisions and explain their reasoning by answering a series of questions (For example see Zeidler et al., 2002; Bell and Lederman, 2003). This strategy, coupled with interviews with which to clarify students’ responses, has produced noteworthy results up until now. Scenarios allow students to familiarise themselves with the main details of the SSI in a short time, while the open questions open up the possibility to explore the reasoning processes students use for decision-making.

3.5.2. Design

The design of the questionnaires was inspired by the one used by Bell and Lederman (2003). The questionnaire consisted of a series of scenarios. Each scenario consists of a short text (between 300 and 500 words in Spanish) detailing real issues on which students can take a stance (in some cases, fictitious characters were used in hypothetical situations). Scenarios were tested as part of the pilot study in order to determine if students were engaged by them and whether their meanings were understood. After the pilot study, the scenarios and the questions were modified to address any interpretation problems, ambiguities, or lack of relevance of the questions.

Each scenario is followed by 5 to 9 questions, the first of which is, in all scenarios, a question that asks the respondent to state which would be his or her decision. The answer options offered are ‘Yes/No/I don’t know’. (Note: For the well-established science scenarios, the options offered were only ‘Yes/No’.) The remaining questions ask students to justify their decision, explore their thinking about the specific ideas of each scenario (for example, their opinion about the disagreement amongst scientists or their relative trust in the agents involved in the scenario), and probe their views of the NOS relative to pertinent aspects of the scenario at hand. Generally, the ideas of the NOS probed by the questions concerned the social embeddedness of science, its empirical basis, and its tentativeness. The complete scenarios, together with the accompanying questions, are in Appendix B.

The topics selected to be turned into scenarios are all related with health and nutrition. Health topics tend to awaken the interest of people, as demonstrated by the attitude to science, technology and engineering survey commissioned by OTS/Wellcome. According to the results of this survey, more than 91% of the 1839 adults interviewed in the United Kingdom claimed to be interested in health-related topics (Ratcliffe and Grace, 2003). It has also been demonstrated that people in the USA tend to believe in pseudoscientific claims related to health issues (National Science Board, 2002).

A total of 9 scenarios were devised. Three of these are about pseudoscientific issues (diets and weight-loss pills, Aids denialists, quantum medicine); three deal with SSI where the scientific basis is still controversial (cloned cattle, modified humans, mobile phones and health); and three encompass topics in which science is already well-established, but that nevertheless present students with a dilemma that requires them to make a decision (self-medication, smoking, diet and diabetes). The scenario on smoking was adapted from one devised by Bell and Lederman (2003).

The scenarios were divided into three sets. Each set consists of a scenario of each of the three kinds. The grouping was then as follows:

- Set 1: Diets and weight-loss pills, mobile phones and health, self-medication
- Set 2: Quantum medicine, modified humans, smoking
- Set 3: Aids denialists, cloned cattle, diet and diabetes

Each student was given randomly a set of scenarios, to be answered both at the beginning and the end of the course. During the pilot study, it was seen that the order in which the scenarios are presented does not affect the quantity or the quality of answers.

3.5.3. Follow-up interviews

Between one and three weeks after completing the scenarios—both at the beginning and the conclusion of the course—some students were interviewed. Students were not selected deliberately; they offered themselves to be interviewed voluntarily.

Interviews were conducted in a small room at the University A campus at times selected by participating students themselves. When the room was unavailable, interviews were conducted in open spaces. Students were assured that their identities and personal data would remain confidential and that there were no correct or wrong answers; rather, the study was aimed at uncovering their thoughts and ideas. Generally speaking, students answered the questions about the issues presented in a candid and open fashion. Interviews lasted between 15 and 25 minutes, depending on students' disposition to talk.

The script of the semi-structured interviews was based on responses given by students to the decision-making questionnaire. The questions asked students to explain, broaden or justify their answers to the scenarios' questionnaires.

3.5.4. Analysis of the data

All answers to the questionnaires and interviews were transcribed to electronic files. Closed, 'Yes/No/I don't know' answers were quantified.

Due to the exploratory nature of this project, the constant comparative method (Lincoln and Guba, 1985) was used to analyse open responses to questionnaires and interviews. The answers used to construct the categories were those obtained at the beginning of the course. The answers from the questionnaires applied at the end of the course were then examined using the derived categories.

The analysis of the data was performed using the Atlas Ti qualitative analysis software. The constant comparative method consists of a series of comparisons among the data from which categories are generated. The first step in the process consists in selecting 'units of information'. In this study, a unit of information was defined as students' complete answer to the written questionnaires, due to the fact that they were very brief and, in general, did not exhibit a variety of ideas. Afterwards, each of these answers was given an individual code, according to the idea they dealt with. During this step, a large number of different codes were generated.

The next stage in the analysis process consisted of grouping the aforesaid codes in broader categories, based on common characteristics. This process was very laborious and time-consuming, since there were no a priori categories. These were generated, modified, and revised gradually, as the various codes were analysed and compared amongst themselves. As more and more comparisons were made, the inclusion and exclusion criteria for the various categories were defined more precisely. At the end of this process, all units of information grouped in each category were revised again, to insure their membership to a given category. As a result of this step, some responses were re-categorised. The generated categories were then compared amongst themselves to detect overlaps, similarities, and interrelationships.

This method is similar to the one used by Zeidler et al. (2002) to determine how the views of the NOS affect the way students weigh contradictory evidence.

To compare the use of the categories between the groups of students, Bell and Lederman (2003) suggested determining the frequencies of category usage in each case. This method, applied to the present study, allowed a clear comparison of the categories used in each of the scenarios, as well as of the categories used before and after the course. All categories are exemplified by means of quotes, to enable their scrutiny and discussion. The fact that frequencies arrived at are drawn from a qualitative analysis, and that there are few answers per category, make a statistical analysis of frequencies unadvisable.

Validity: To increase the validity of the analysis, a fairly large sample (93 pairs of decision-making questionnaires from before and after the course) was used. Apart from written responses, 20 students were interviewed in order to further clarify or develop their responses. Interviews with teachers constituted a third source of data.

a) Determining the influence of the context

In order to determine if different factors or ideas play a role in students' thinking in a context-dependent way, the categories used in each of them, by each student and for each context—well-established science, pseudoscience, and SSI— were compared.

b) Determining the influence of the course

In order to determine if the 'Science and Society' course had an effect on the factors or ideas used by students as a basis for making a decision, the categories used in each scenario before and after the course were compared.

c) Analysis of the relationship between students' decisions and their justification

To examine if specific decisions were associated with certain categories of justifications, responses (Yes/No/I don't know) were plotted against the type of justification given in each scenario. These graphs allowed detecting and highlighting the role different ideas play in students' decisions, as well as comparing responses across scenarios.

d) Analysis of students' patterns of response

In order to determine whether students responses to the three scenarios are consistent, and whether they can be classified according to their patterns of response across different scenarios, a two-step cluster analysis was performed with the aid of SPSS software. To perform the analysis, the categories extracted from students' body of justifications were used.

3.6. The study

3.6.1. The sample

For this study, two groups from the 'Science and Society' course were selected. The groups were selected because the teachers volunteered to participate. Most students studying this subject were first-term students that have just entered college, and could be studying for a degree in Chemistry, Pharmaceutical and Biological Chemistry, Chemical Engineering, Food Chemistry, or Metallurgy and Chemical Engineering.

The first group consisted of 68 students, 35 women and 33 men. The average age was 18.5 years. The majority of students came from public schools and only three from private schools. Both teachers had studied Chemical Engineering as undergraduates. One of them had subsequently specialised in education and worked in the field of teacher education for more that 20 years. One of her areas of interest is the NOS, and she strongly advocated the acceptance of the subject as part of undergraduate curricula. She has been teaching 'Science and Society' since its inception in 2006. The other, younger, teacher lacks teaching experience. The term during which the study took place was the only the second she had taught the subject.

The second group consisted of 60 students, 30 women and 30 men. The average age was 18.3 years. The majority of students also came from public schools; only ten came from private schools. Both teachers had degrees in the humanities, having studied a Master degree in Philosophy of Science. They had taught the subject for 4 terms.

3.6.2. Data collection

This study was conducted between the months of September and December, 2009.

In the first group, 40 students completed both sets of questionnaires. The first application was in the classroom, while the second had to be assigned as homework, as the teacher was running out of time to complete the programme of the course.

In the second group, 53 students completed both sets of questionnaires. In this group was possible to apply all the instruments in the classroom. Both open responses and SUSSI questionnaires were transcribed into electronic files.

A total of 26 interviews were performed at the beginning of the course. At the end of the course only 20 interviews were completed. Interviews and informal conversations with teachers were also carried out. Interviews were conducted in either an office or an empty classroom where the student could express him or herself freely. Some interviews were conducted in open spaces when neither office nor classroom was available. All interviews were transcribed into electronic files for their analysis.

Chapter 4. Students' views about the nature of science: results and analysis.

4.1. Rationale

Among several other educational outcomes, at the conclusion of the course Science and Society—part of the syllabus of those undergraduate students that took part in this project—students should 'understand the social and human dimensions of scientific and technological activities'. They also should be able to 'analyse the relationships between science and society from a standpoint that incorporates insights from actual science, philosophy, history, and sociology of science'. As a result, students can 'become citizens capable of making informed and reasoned decisions within a democratic society'.

The objectives of the course agree with the notion—expounded by several authors—that a better understanding of the NOS helps students analyse and solve problems that have a socioscientific component (Kolstø, 2001; Sadler et al., 2002; Bell and Lederman, 2003).

The syllabus of Science and Society makes no explicit mention of any particular aspect of the NOS. However, among the topics touched upon in its first programmatic unit (An Introduction to Science, Technology, and Society) are (a) general aspects about science, technology, and society; (b) historical aspects of science; (c) historical aspects of technology; (d) characteristics of the modern scientist; and (e) science and humanism—how to establish a dialogue between the two cultures? Clearly, instruction on the NOS is included implicitly in these topics.

With the aim of researching the effect of the course Science and Society on the views about science held by students, the questionnaire Student Understanding of Science and Scientific Inquiry (SUSSI)—developed and validated by Liang et al. (2008; see Appendix A)—was administered at the beginning and at the end of the course. A discussion of evidence (or lack thereof) of a relationship between students' views of the NOS—as assessed through SUSSI—and the way in which students solve socioscientific and pseudoscientific issues follows in the next chapters.

4.2. Characteristics of the SUSSI questionnaire

SUSSI was originally developed for research into the views of the NOS held by pre-service teachers. Age proximity and an above average knowledge of specialised scientific matters are factors that, in principle, make SUSSI an adequate choice to probe the views of undergraduate science students—compared with other available assessment instruments. The questionnaire covers six aspects of the NOS: observations and inferences, tentativeness, scientific theories and laws, social and cultural embeddedness, creativity and imagination, and scientific methods (a detailed description of these aspects is presented in the rubric designed to assess responses to open questions, below). Although well-supported in the literature, the selection of aspects constitutes one of its main limitations, as a reading of McComas (1998) and Osborne et al. (2003) attests. SUSSI omits important aspects of the NOS, such as the explanatory aim of science, the need for clear and explicit presentation of results, the systematic records of activities kept by scientists, the role played by peer-review of results in the validation of scientific knowledge, the nature of the relationship between science and technology (McComas et al., 1998, p. 6), and the role played by questions, predictions and evidence in science (Osborne et al., 2003).

Due to the broad range of issues that comprise the consensus on what should be taught about the NOS, a questionnaire that centres on only six aspects will, by necessity, provide a limited perspective on students' views. Nevertheless, the topics that SUSSI actually covers are part of the educational consensus on the NOS, pertinent and relevant enough so as to be included in science curricula. In that sense they provide a more or less comprehensive panorama of the views of respondents (McComas et al., 1998; Osborne et al., 2003).

The SUSSI questionnaire has several advantages, one of which is that it can be applied easily to large groups of students that can, in their turn, answer it quickly (15-30 minutes). Furthermore, the questionnaire's items allow for triangulation, that is, the combination of Likert-type items with open-response items increases the test's reliability and provides a more comprehensive view of what students believe about science (Liang et al., 2008).

In the case of SUSSI, Likert-type items are graded by assigning a value of 5 to informed viewpoints and a value of 1 to naïve ones. For the negative statements, care must be exercised so as to adequately represent students' views. In what follows, the sets of statements for each aspect of the NOS are shown, followed by their categorisation as either positive (i.e., when 'strongly agree' equals 5 points) or negative (i.e., when 'strongly agree' equals 1 point; Table 6).

Table 6 Categorisation of the statements of SUSSI

	1. Observations and Inferences	
A.	Scientists' observations of the same event may be different because the scientists' prior knowledge may affect their observations.	(+)
B.	Scientists' observations of the same event will be the same because scientists are objective.	(-)
C.	Scientists' observations of the same event will be the same because observations are facts.	(-)
D.	Scientists may make different interpretations based on the same observations.	(+)
	2. Change of Scientific Theories	
A.	Scientific theories are subject to an on-going testing and revision.	(+)
B.	Scientific theories may be completely replaced by new theories in light of new evidence.	(+)
C.	Scientific theories may be changed because scientists reinterpret existing observations.	(+)
D.	Scientific theories based on accurate experimentation will not be changed.	(-)
	3. Scientific Laws vs. Theories	
A.	Scientific theories exist in the natural world and are uncovered through scientific investigations.	(-)
B.	Unlike theories, scientific laws are not subject to change.	(-)
C.	Scientific laws are theories that have been proven.	(-)
D.	Scientific theories explain scientific laws.	(+)
	4. Social and Cultural Influence on Science	
A.	Scientific research is not influenced by society and culture because scientists are trained to conduct pure, unbiased studies.	(-)
B.	Cultural values and expectations determine what science is conducted and accepted.	(+)
C.	Cultural values and expectations determine how science is conducted and accepted.	(+)
D.	All cultures conduct scientific research the same way because science is universal and independent of society and culture.	(-)
	5. Imagination and Creativity in Scientific Investigations	
A.	Scientists use their imagination and creativity when they collect data.	(+)
B.	Scientists use their imagination and creativity when they analyse and interpret data.	(+)
C.	Scientists do not use their imagination and creativity because these conflict with their logical reasoning.	(-)
D.	Scientists do not use their imagination and creativity because these can interfere with objectivity.	(-)
	6. Methodology of Scientific Investigation	
A.	Scientists use different types of methods to conduct scientific investigations.	(+)
B.	Scientists follow the same step-by-step scientific method.	(-)
C.	When scientists use the scientific method correctly, their results are true and accurate.	(-)
D.	Experiments are not the only means used in the development of scientific knowledge.	(+)

In the qualitative section, that is, in the open-response items, answers that exhibited an informed view received 3 points, whereas naïve views received 1 point. Answers that mixed both views were classified as transitional (and were given 2 points). In the following sections, the criteria adopted for the categorisation of answers will be defined.

4.3. The sample

For the present project, the SUSSI questionnaire was administered to two groups at the beginning and at the end of the Science and Society course. Table 7 shows the number of students in each group that completed the questionnaire before and after the course, as well as the number of male and female students and the average age.

Table 7 Number of students, gender and mean age per group at the beginning and at the end of the course.

	Group 1		Group 2	
	Before	After	Before	After
Number of students	68	46	60	51
Female	35	26	30	23
Male	33	20	30	28
Age (mean)	18.5 years		18.3 years	

The decreasing number of students in group 1 (22 students less) was due to time constraints—teachers had to leave the second application of the questionnaire as a homework task. Many students did not hand in their questionnaires.

4.4. Results of the SUSSI questionnaire—Overview

This section presents the results obtained through administration of the SUSSI questionnaire and describes briefly the most relevant findings. In subsequent sections, a more detailed analysis of the results is undertaken. The effect of the course and the differences between groups—regarding their views about the different aspects presented by the questionnaire—are examined, both from a quantitative and a qualitative standpoint.

Calculation of Cronbach's alpha for the full questionnaire yields a coefficient of 0.748. Since the questionnaire comprises six topics with four Likert-type items each, Cronbach's alpha for all six was calculated (Table 8).

Table 8 Cronbach α for each NOS topic in the SUSSI questionnaire.

NOS Topic	Cronbach α
Observations and inferences	0.530
Tentativeness	0.510
Scientific theories and laws	0.305
Social and cultural embeddedness	0.653
Creativity and imagination	0.844
Scientific methods	0.650

In general, the values of Cronbach's alpha are acceptable, considering that each topic of the NOS has only four items. The only exception is found in the section concerning scientific theories and laws (α = 0.305)—this will be analysed in its corresponding section, below.

In order to determine whether the students' views of each group changed as a consequence of the course, responses to the Likert-type items before and after the course were statistically compared using a dependent *t*-test. Table 9 summarises the results. An overview shows that the course did not influence the views of students in group 1, but it did influence the views of students in group 2 regarding (1) the role of creativity and imagination in science and (2) the scientific method.

To explore if both groups had similar or different views both at the beginning and at the end of the course, an independent *t*-test was performed with the responses to Likert-type items as primary data. Table 10 summarises the results. At the beginning of the course, there were no differences in the views students held about observations and inferences, the tentativeness of science, scientific laws and theories, and creativity in science. There were, however, differences at the outset regarding the social and cultural embeddedness of science and the scientific methods, with group 2 exhibiting more developed views in both instances. At the course's ending, the differences regarding the social and cultural embeddedness between both groups disappeared, but the corresponding difference regarding the scientific methods increased. Furthermore, a difference between groups in their views regarding observations and inferences appeared—group 2 actually improved its views in this matter.

Table 11 summarises the percentages of naïve, transitional, and informed views students exhibited in the responses to the open questions for each topic. Subsequent sections will detail the characteristics that were considered to classify responses as naïve, transitional or informed in the case of each topic, with choice quotes of students as examples.

When the student did not respond or responded 'I don't know', the answer was categorised as 'Non-classifiable'. Group 1 exhibited a higher percentage of non-classifiable responses, compared with group 2. In both, for all topics of the NOS, the percentage of non-classifiable responses decreased at the end of the course. In the sections dealing with observations and inferences and the tentativeness of science, more than half of students in both groups were classified as having informed views. On the contrary, all students exhibited naïve views regarding the relationship between theories and scientific laws. In the topics of observations and inferences and social and cultural embeddedness, the percentage of students with an informed view decreased, in both groups, at the end of the course. In contrast, in both groups there was an improvement in their views about scientific methods.

Table 9 Comparison of student responses to Likert-scale items by group

	Group 1 (n=46)*							Group 2 (n=51)*							
	Initial		Final					Initial		Final					
NOS topic	M	SD	M	SD	*t*(45)	p	r	M	SD	M	SD	*t*(50)	p	r	*Summary*
Observations and inferences	13.91	2.67	13.80	2.50	0.239	0.812	0.036	14.76	2.86	14.94	2.66	-0.388	0.700	0.055	G1i=G1f/G2i=G2f
Tentativeness	15.09	2.46	14.41	2.75	1.399	0.169	0.204	15.10	2.25	15.59	2.56	1.399	0.168	0.194	G1i=G1f/G2i=G2f
Scientific theories and laws	9.09	1.81	9.72	5.52	-1.665	0.103	0.241	10.27	2.51	10.27	2.21	0.000	1.00	0	G1i=G1f/G2i=G2f
Social and cultural embeddedness	12.90	3.37	13.07	3.33	-0.352	0.727	0.052	14.02	2.74	13.88	3.24	0.341	0.735	0.048	G1i=G1f/G2i=G2f
Creativity and imagination	12.96	4.36	13.35	3.69	-0.569	0.513	0.098	12.59	3.63	13.67	3.78	-2.412	0.020	0.323	G1i=G1f/G2i<G2f
Scientific methods	11.43	3.23	12.17	2.32	-1.435	0.158	0.209	13.75	3.70	15.27	2.31	-3.110	0.003	0.403	G1i=G1f/G2i<G2f

Means (M), standard deviations (SD), dependent t-tests (t), two-tailed significance and effect sizes (r).
For this analysis only students who answered the questionnaires at the beginning and at the end of the course were considered.
To be considered significant p<.05
G1: Group 1; G2: Group 2; i: Initial; f: Final

Table 10 Comparison of students responses to Likert-scale items by time of application

	Before							After							
	Group 1 (n=67)		Group 2 (n=60)					Group 1 (n=46)		Group 2 (n=51)					
NOS topic	M	SD	M	SD	*t*(125)	p	r	M	SD	M	SD	*t*(95)	p	r	*Summary*
Observations and inferences	14.31	2.61	14.72	2.79	-0.841	0.405	0.075	13.80	2.50	14.94	2.66	-2.161	0.033	0.216	Initial:G1=G2/Final:G1<G2
Tentativeness	15.19	2.55	15.25	2.27	-0.130	0.897	0.012	14.41	2.75	14.59	2.56	-0.325	0.746	0.033	Initial:G1=G2/ Final:G1=G2
Scientific theories and laws	9.27	2.29	10.03	2.46	-1.814	0.072	0.160	9.72	2.52	10.27	2.22	-1.158	0.250	0.118	Initial:G1=G2/ Final:G1=G2
Social and cultural embeddedness	12.84	3.23	14.25	2.80	-2.625	0.01	0.229	13.07	3.33	13.88	3.24	-1.224	0.224	0.125	Initial:G1<G2/ Final:G1=G2
Creativity and imagination	13.03	3.95	12.43	3.77	0.868	0.387	0.077	13.35	3.69	13.67	3.78	-0.419	0.676	0.043	Initial:G1=G2/ Final:G1=G2
Scientific methods	11.93	3.04	13.67	3.53	-2.988	0.003	0.258	12.17	2.32	15.27	2.31	-6.589	<.001	0.560	Initial:G1<G2/ Final:G1<G2

Means (M), standard deviations (SD), independent t-tests (t), two-tailed significance and effect sizes (r).
To be considered significant p<.05
G1: Group 1; G2: Group 2.

Table 11 Percentages of students' non-classifiable, naïve, transitional and informed views by NOS topic, by group and by time of application.

	Non-classifiable (%)				Naïve views (%)				Transitional views (%)				Informed Views (%)			
	G1i	G1f	G2i	G2f	G1i	G1f	G2i	G2f	G1i	G1f	G2i	G2f	G1i	G1f	G2i	G2f
Observations and inferences	12	7	2	0	19	33	28	27	9	17	10	27	60	43	60	45
Tentativeness	15	11	3	0	12	20	13	18	9	13	13	12	64	57	70	71
Scientific theories and laws	25	17	7	4	72	76	88	92	3	4	5	4	0	2	0	0
Social and cultural embeddedness	27	13	7	4	12	15	15	12	4	28	33	51	55	43	45	33
Creativity and imagination	31	15	8	4	16	35	30	29	16	28	35	27	36	22	27	39
Scientific methods	28	20	13	4	39	33	18	14	22	20	17	22	10	28	52	61

G1: Group 1; G2: Group 2; i: Initial; f: Final

4.5. Students' views about observations and inferences

According to the authors of SUSSI (Liang et al., 2008, Appendix B):

> Science is based on both observations and inferences. Observations are descriptive statements about natural phenomena that are directly accessible to human senses (or extension of those senses) and about which observers can reach consensus with relative ease. Inferences are interpretations of those observations. Perspectives of current science and the scientists guide both observations and inferences. Multiple perspectives contribute to valid multiple interpretations of observations.

The course had no statistically significant effect on any of the groups regarding this particular topic. However, at the end of the course group 2 did show a slight improvement with respect to group 1 ($p < 0.05$; effect size: 0.22).

A more detailed analysis of responses revealed that, in both groups, before and after the course, the majority of students agreed with the notions that observations can differ according to scientists' previous knowledge (statement 1A) and that their interpretations of the same observation can also vary (statement 1D). Half of students (both before and after the course) distinguished observations from facts (statement 1C)—a notable difference was that in group 2 the majority of students (65 per cent) disagreed with the notion that observations must be the same because scientists are objective (statement 1B), whereas in group 1 less than half of the students (42 per cent) shared this view. At the end of the course still less students of group 1 (30 per cent) disagreed with the idea that scientists are objective.

The responses to the open questions were categorised according to the above-mentioned definition developed by the authors. In the following paragraphs some samples of responses corresponding to the three categories are shown:

a) Students whose responses were categorised as naïve views argued that observations and facts are the same thing. Other students suggested that the scientists' diverging observations of the same phenomenon are due to changes made to experimental conditions, or to experimental errors, or to the lack of skill of scientists.

> An observation differs depending on how the experiment is made [1.2/i].
>
> They are the same [observations and interpretations] because in an investigation you find the results of the same question [2.44/i].

b) Some students mixed informed views with naïve ones. These views were categorised as transitional. For example, students that suggested that there are differences in the observations made of the same phenomenon—although that is not an adequate scientific practice.

> Each [scientist] can have a different religious education that stops him or her from following an objective path [1.37/i].
>
> Well, each scientist has his or her own way of interpreting things; besides, results can vary because one scientist might catch something another misses [1.2/f].

c) Several students used examples discussed in class as a basis for their views—the majority of those that did so exhibited an informed view and used the example adequately. Students relied mainly on the episodes of spontaneous generation (Pasteur and Pouchet), atomic theory, the opposing ideas of Priestley and Lavoisier, the discovery of Neptune, the ideas of Galileo and Copernicus about the heliocentric and geocentric theories, the dual nature of light, the exclusion of Pluto as one of the planets of the Solar System, and the building of the periodic table of the elements. The frequency of use of taught examples from the history of science decreased in responses given at the end of the course (thirteen students from group 1 and four from group 2). Other responses were categorised as belonging to an informed view even though no examples taught in class were mentioned, so long as explicit mention was made that observations and inferences can vary and that these depend on the perspectives and the previous knowledge of scientists.

> With the example of Pouchet and Pasteur we can notice the difference of interpretation of the same phenomenon [1.12/i].
>
> When seeing how the rain falls one could observe the speed of the falling drops and interpret it. Another person can see the same rain but fail to notice the speed of the drops and rather see why it rains

> and give his or her observations and these two would be different [1.13/i].

Responses to open questions allow probing deeper into the views of students. For instance, approximately 90 per cent of students agree that scientists' interpretations can be different amongst themselves even though they might be based on the same observations (Statement 1D; the right answer, according to the authors of SUSSI). However, in responses to the open questions it can be seen that several students thought that the cause(s) of this discrepancy in interpretation was due to error, ignorance, or incompetence on the part of scientists—a naïve view of the issue.

The above notwithstanding, patterns of response to the Likert-type items and written responses were very similar. Approximately half of students exhibited an informed view, and one third had naïve views about the issue. The percentage of students with naïve views regarding this issue increased at the end of the course in group 1 (Table 11). In both groups the percentage of students with informed views decreased at the end of the course, while, simultaneously, the number of students with transitional views increased.

4.6. Students' views about the tentativeness of science

The definition provided by the authors of SUSSI for the tentativeness of science that was used to evaluate the responses to open-ended questions is:

> Scientific knowledge is both tentative and durable. Having confidence in scientific knowledge is reasonable while realizing that such knowledge may be abandoned or modified in light of new evidence or reconceptualization of prior evidence and knowledge. The history of science reveals both evolutionary and revolutionary changes (Liang et al., 2008, Appendix B).

In this instance, the course failed to have an effect on students' views regarding the tentativeness of science (Table 9). Neither were there any differences between groups, before and after the course (Table 10). Nevertheless, the means in all cases—both groups, before and after—for this topic were the highest (around 15 points, with a maximum of 20) recorded, compared with the means of the rest of the topics. These results suggest that, from the very beginning, students recognise that scientific knowledge is provisional.

Even though the majority of students got a high score on this topic, there was a notable difference between the four statements that comprise this topic. The majority of students—between 74 and 93 per cent—of both groups (before and after the course) agreed that scientific theories are subject to continuous revision (statement 2A) and that they can be replaced completely in the light of new evidence (statement 2B). However, only about half the students agreed that one of the causal reasons of change is that scientists reinterpret existing observations (statement 2C). More than half of students believed that a theory that is based on precise experiments will not change in the future (statement 2D).

In responses to open-ended questions, the number of students with informed views was similar to what would be expected given the high mean scores of Likert-type items (of between 57 and 71 per cent; Table 11).

a) Students whose views were categorised as naïve mentioned that theories do not change. Students that said that theories do change because the object of study itself changes were also included in the naïve category.

> The theory of relativity was built on a solid base, which makes changing it practically impossible [1.18/i].
>
> Each theory that is presented is in constant revision and change, since phenomena that were previously analysed for the purposes of the theory change themselves; that's why they need to be modified [1.16/f].

b) It was considered that students had a transitional viewpoint when they pointed out that theories do not change, they are only improved. Likewise, transitional views were those that posited that change in scientific theories depends on having contradictory results from an experiment.

> With new arguments about research and with better information I think that [theories] are not always abandoned; rather, they are improved [1.10/i].

c) Students' views were categorised as informed when they noticed that theories can change for a variety of reasons and under different circumstances. In some cases, students relied on examples that had been taught in class. In some of these, the details of the episode were correct, but there were also students that got their details wrong. An answer was categorised as correct if the student made adequate reference to change related to theories, whether or not the details of the example were accurate. Examples mentioned by students were the discovery of the cause of puerperal fever, the discovery of oxygen, spontaneous generation, the heliocentric and geocentric theories, evolution, changes in atomic theory, relativity, phlogiston, the exclusion of Pluto as a planet, the building of the periodic table of the elements. In the case of tentativeness, the number of examples used by students before and after the course did not vary in any important way.

> For example, the thing about puerperal fever was that some [doctors] believed that it wasn't true that women died for a lack of hygiene, but when bacteria were studied, it was found that whoever had explained this theory was right [2.52/i].
>
> Theories are models that describe phenomena and observations, and they can change when the phenomenon is observed more, when new research is done, and according to the needs of the time. Even though planet Earth is not actually flat, abstractions of this kind are useful for some practical purposes [2.36/i].

One of the problems that stem from the comparison of Likert-type items and open-ended responses, in the case of the tentativeness of scientific knowledge, is that a given student can think that theories change for the wrong reasons, such as when students believe that theories change because the object of study is constantly changing.

4.7. Views of students about scientific theories and laws

Liang et al. argue that:

> Both scientific laws and theories are subject to change. Scientific laws describe generalized relationships, observed or perceived, of natural phenomena under certain conditions. Scientific theories are well-substantiated explanations of some aspects of the natural world. Theories do not become laws even with additional evidence; they explain laws. However, not all scientific laws have accompanying explanatory theories (Liang et al., 2008, Appendix B).

The course had no impact on students' views about the relationship between theories and laws (Table 10). In fact, this topic is the one with the lowest means (9 to 10 from a maximum of 20). Also, there were no significant differences between groups before or after the course.

Generally speaking, between half and three quarters of students (before and after the course) answered that scientific theories exist in the natural world and are discovered by means of scientific investigations (statement 3A) and that scientific laws do not change (statement 3B). Almost all students (75-90 per cent) consider that theories become laws. For these three statements, the majority of students exhibited a naïve view. However, approximately half of them agreed with statement 3D—scientific theories explain scientific laws. This discrepancy within answer patterns decreased the value of Cronbach's alpha (0.305). If statement 3D were to be eliminated from the calculation, Cronbach's alpha would rise to a value of 0.517.

In responses to open-ended items, students relied on examples of several laws and theories they are familiar with, such as the laws of gravity, of Newton, and of gases, relativity and evolutionary theories—among others. However, in no case did students use an example to provide an explanation that corresponded to an informed view. In this topic there was a clear trend:

a) The highest percentage of students offered views categorised as naïve, both before and after the course (72-92 per cent, Table 11)—theories become laws once there has been sufficient confirmation of a theory. Other students argued that theories cannot be confirmed whereas laws can.

> The theory of relativity is a theory because we don't have the technology to prove it. The laws of Newton can be proved through experimentation, which doesn't mean they won't change eventually because after all they are just approximations to nature, not nature itself [2.2/f].

b) Views were categorised as transitional when students talked about how theories involve a higher level of abstraction compared with laws, but did not specify the relationship between both. This category was also given to those students that repeated the idea that theories explain laws, even though they failed to offer examples or further elucidation.

> We could say that laws are simpler, because confirming them is easy and palpable. However, theories are more complex and abstract—not so palpable [1.36/f].
>
> Because theories are the basis for understanding laws [1.60/f].
>
> Scientific theories are possible explanations of things with which it's unlikely we can make experiments. But, they are based on theoretical knowledge (for example, the origin of life or of the universe). Laws are the ones that are stated with support from experimentation, such as the laws of the gases or the laws of thermodynamics [1.15/f].

c) Only one student answered this question with views that can be categorised as informed:

> Laws are something concrete with a scientific basis. What theories do is try to explain the why of these laws and give support the laws [1.8/f].

In spite of the fact that approximately half of students of both groups scored higher in the item that states that scientific theories explain laws (statement 3D), only one student explicated this issue to answer the open-response item.

4.8. Views of students about the social and cultural embeddedness of science

In the rubric devised for the evaluation of open-response items, the authors say that:

> Scientific knowledge aims to be general and universal. As a human endeavour, science is influenced by the society and culture in which it is practiced. Cultural values and expectations determine what and how science is conducted, interpreted, and accepted (Liang et al., 2008, Appendix B)

In this topic, the course did not have an effect on any of the groups. At the beginning, group 2 overcame group 1 ($p = 0.01$; effect size: 0.23), but at the end of the course the difference between the groups disappeared (Table 9 and Table 10).
At the start of the course, the more marked difference between both groups was located in statements 4A and 4D. The first statement notes that research is not influenced by culture because scientists are objective. The second statement claims that all cultures carry out research in the same way. One half of group 1 agreed with both statements, whereas only one fourth of group 2 did so. At the end of the course, these differences disappeared, with group 1 slightly improving and group 2 having decreased their score.

Regarding the open-response items, the percentage of informed views decreased in both groups after the course and the transitional views increased in the same proportion (Table 11). Few students relied on examples seen in class for their responses. Those that did, referred to evolutionary theory, puerperal fever, war-time research, nuclear energy, cloning, the study of specific diseases (obesity and cancer, for instance). However, most responses were vague and did not cite concrete examples.

a) A view was taken to be naïve when students mentioned that science should be kept isolated from culture and society.

> Culture doesn't affect science. Science is universal and an example of it is Einstein—he was Jewish, his religion and his culture didn't affect his investigations [2.7/f].

> Supposedly, one is free to choose a research topic—of course, to do good and use it adequately [2.40/i].

b) Students that brought up a unilateral relationship in which science affects society, such as, for example, that science exists to solve problems were classified as transitional.

> Scientific and technological problems always are made to satisfy the needs of society or to make work easier [2.10/f].

> Science must be true and go beyond cultural beliefs even though, in real life… Yes, science will be affected by its social context [1.56/i].

c) When students pointed out that society influences science according to the historical context, beliefs, political, economic, and social interests, their views were categorised as informed.

> Society sometimes says that what science is trying to discover is proper or improper. Example: [in its time] the publication of 'The Origin of the Species' [2.60/f].

> […] science is made by men and women, cultural and social beings. That's why scientific research is involved in decision-making in social issues and vice versa [1.36/f].

The results obtained in the open-ended items were consistent with the scores obtained in the Likert-type items for this topic.

4.9. Views of students about creativity and imagination in science

When the SUSSI questionnaire was designed, its authors conceived the role of creativity and imagination in science as follows:

> Science is a blend of logic and imagination. Scientific concepts do not emerge automatically from data or from any amount of analysis alone. Inventing hypotheses or theories to imagine how the world works and then figuring out how they can be put to the test of reality is as creative as writing poetry, composing music, or designing skyscrapers. Scientists use their imagination and creativity throughout their scientific investigations (Liang et al., 2008).

The course did have an impact in this topic in group 2, improving slightly their views at the end of the course ($p < 0.05$; effect size = 0.32; Table 9). However, the difference was not so big as to make it much different from group 1, who did not register an improvement at the end of the course (Table 10). On average, approximately half the students provided informed views on all four statements. Both groups improved their views in statement 5D that deals with imagination and creativity regarding objectivity. Group 1 besides showed improvement in their views regarding statement 5C, the one that links imagination and creativity with logical reasoning. Group 2 did not show any difference—before and after—in that statement, but did improve in statement 5A dealing with the role of imagination and creativity in data collection.

a) Students whose views were categorised as naïve replied that imagination and creativity do not play a role in science.

> I think that science is more objective and reasoned than imaginative and creative. A biologist didn't use his or her imagination to know how cells are like—he or she did it by making observations and using his or her reasoning [1.27/i].
>
> They [scientists] must not imagine things; they need to prove what they say [1.32/i].

b) Transitional views include those that accept that imagination and creativity exist within scientific work, but only to a limited extent: in hypothesising, predicting the results of an experiment, or inventing new technology.

> Well, they [scientists] use it when they imagine how is it that the experiment will turn out [1.22/i].
>
> Imagination and creativity can be used in hypotheses [2.16/i].

c) In order to be categorised as informed, students' views must imply that imagination and creativity are involved in more processes than just technological applications and innovations. Few students used examples seen in class, such as evolutionary theory, Einstein's theory of relativity, and atomic models.

> They [scientists] do use it [imagination], for example when Darwin used birds to confirm adaptation to other environments; he had to be creative to make that experiment [1.18/i].
>
> Who has seen an atom? In order to work with them, you have to imagine them [1.51/i].

Despite having studied the topic in class, some of the examples mentioned did not necessarily illustrate the point being made adequately. For instance:

> In the case of Mendeleiev and his prediction of the elements, he didn't use his imagination but rather relied on his observations [2.15/i].

4.10. Views of students about scientific methods

In the rubric developed to evaluate open-ended responses regarding scientific methods, the authors claimed that:

> Scientists conduct investigations for a wide variety of reasons. Different kinds of questions suggest different kinds of scientific investigations. Different scientific domains employ different methods, core theories, and standards to advance scientific knowledge and understanding. There is no single universal step-by-step scientific method that all scientists follow. Scientists investigate research questions with prior knowledge, perseverance, and creativity. Scientific knowledge is gained in a variety of ways including observations, analysis, speculation, library investigation and experimentation (Liang et al., 2008, Appendix B).

This topic was the one on which the course had the greatest impact, even though only in group 2—views significantly improved ($p < 0.005$; effect size: 0.4; Table 9). Group 2 exhibited a difference compared with group 1 since the first application ($p < 0.005$; effect size: 0.26). This difference increased notably at the end of the course ($p < 0.001$; effect size: 0.56; Table 10).

The observed global differences between groups are due to differences in their answers to the four items that comprise this particular section. The item that received the highest proportion of informed answers in both groups was 6A, the one that says that scientists use a variety of methods to obtain results (63 and 94 per cent at the end for groups 1 and 2, respectively). In the first administration, half the students in group 2 agreed that the scientific method must be followed step by step (statement

6B), whereas 72 per cent of group 1 held that viewpoint. The views regarding this item improved at the end in group 2 (71 per cent of students held informed views), but not in group 1. There were also differences regarding statement 6C saying that if the scientific method is followed adequately, the results will be accurate and true. 80 per cent of group 1 agreed with this notion at the beginning of the course, whereas in group 2 only 53 per cent of student held that view. At the end, views improved a little and in group 1, 70 per cent of students agreed with that view—only 35 per cent in group 2. At the beginning, there were no significant differences between groups towards the idea that experiments are not the only way to obtain scientific knowledge (statement 6D), but at the end of the course the score of group 2 overcame that of group 1 (75 against 54 per cent, respectively).

Open-ended items also reflect the difference between both groups (Table 11). Whereas group 2 had 52 and 61 per cent of informed views (at the beginning and at the end of the course, respectively), group 1 had 10 and 28 per cent (idem). Likewise, group 2 had a lower proportion of naïve views (14 per cent at end of the course) in contrast with group 1 (33 per cent at the end).

a) A response was categorised as naïve when students mentioned that there is a unique and universal scientific method. Also categorised as naïve were those responses that confused methods and specific experimental techniques.

> Scientists do use a method to perform their experiments. However, it depends on what one wants to do. In order to use a method, for example, there are different methods for separating mixtures an not a single universal one [2.28/f].
>
> I think that the majority of scientists base their experiments on the scientific method [1.25/f].

b) Views were categorised as transitional whenever they mixed the possibility of using a variety of methods while still keeping the idea of a universal method.

> I think that the scientific method can be used, but it can deviate from the procedure in order to deduce other things [1.54/f].

> There are times when the scientific method is not used and things are discovered accidentally, like penicillin [2.38/i].

c) Informed views were those that mentioned examples of scientists that did not follow the traditional scientific method. The more used examples were the discovery of penicillin, the building of the periodic table, and the photoelectric phenomenon.

> There are a variety of methods, for example, the creation of the periodic table or the invention of penicillin. These discoveries didn't follow the scientific method [2.8/f].

> Not everything can be experimented upon and proved. However, one can build models that help to explain and predict results [2.36/f].

In summary, the questionnaire proved to be a valid and useful tool with which to determine students' views. One of its main limitations, inherent to all selected-response questionnaires, is the variability of students' interpretations of the items. However, thanks to the open-ended items, students' views could be probed in-depth.

The majority of students exhibited naive views about the NOS, especially in the topic of the relationship between laws and theories. The course had a restricted effect on students' views: only in Group 2 did students improve their views regarding the role of creativity in science and the scientific method. Results suggest that changes in students' views are temporary, given that in many cases their views at the end of the course were more naïve that and the number and variety of examples provided by students decreased.

In the next chapter the influence of the views of the NOS on the decisions students make about pseudoscientific, socio-scientific and well established science is analysed. In Chapter 6, the results will be discussed in the light of the pertinent literature.

Chapter 5. Decision-making questionnaire: Results and Analysis

The decision-making questionnaire (DMQ) was devised with the aim of ascertaining the decisions students make regarding a variety of topics and the reasons that led them to make those decisions. The questionnaire explores, furthermore, students' ideas about particular aspects of each topic.

As described previously in the section on methods, the questionnaire comprises nine scenarios: three pseudoscientific ones, three SSI ones, and three well-established science ones. Each student completed a scenario of each kind both at the beginning and at the end of the course.

In this chapter, the results obtained through the DMQ are presented and analysed. The chapter is organised in six sections. The first one is dedicated to a brief discussion of the analysis of the qualitative data obtained from the DMQ. The following three sections cover students' responses and justifications to the different types of scenarios, that is, pseudoscience, SSI, and well-established science. In the fifth section, the three different scenarios are analysed in search of a pattern in students' responses. Finally, in the last section the most relevant findings are summarised in the light of the initial research questions.

All through the chapter, the issue of whether students use their ideas about the NOS to make decisions is explored—in all the scenarios. Also, whether these ideas influence decision-making will be considered. Furthermore, the use of different kinds of justifications in each scenario will be contrasted, before and after the course. Finally, the influence of the scenarios themselves on decision-making and justifications will be also explored.

5.1. Analysis of the data

5.1.1. Students' decisions

For this project, the researcher worked with two groups of first-year undergraduates studying a course called 'Science and Society' in University A, a public university in Mexico City. In total, 9 scenarios (three about pseudoscience, three about SSI, and three about well-established science) were designed, each with its corresponding set of questions (Appendix B). In both groups, each student read three scenarios (one from each kind) and completed the questionnaires. After reading the scenario, the first question asked the student to make a decision related to the topic at hand, by selecting one of the options offered: 'Yes/No/I don't know'. Each student answered the same three scenarios at the beginning and at the end of the course.

In order to determine if the course affected the decisions made by students, the proportions of students that answered either 'Yes', 'No', or 'I don't know' were compared. Unfortunately, in Group 1 there was an important difference in the number of students that completed the questionnaires at the beginning and at the end of the course. This was due to the fact that the second administration of the three scenarios/questionnaires could not be done during class hours by the teachers—they just could not find the time to administer them. The scenarios and questionnaires were thus left as homework. As a result several students forgot to hand them in. Furthermore, some students forgot to bring to school the set of three scenarios/questionnaires and, in order to comply with the deadline, photocopied and handed in different sets from the ones completed at the beginning of the course. For this reason, the analysis of the proportions of students' responses will be done only with those students that completed both sets of questionnaires.

The results from the number of students that chose each option do not necessarily reflect how many students changed their decisions, nor the direction in which they changed them. They only show the overall proportion of students that chose each answer.

5.1.2. Categorisation of students' justifications

In this section, the analysis of the justifications given as grounds for decision-making is described in detail, together with the category-extracting process from students' responses.

The purpose of the second question of the instrument was to elicit students' justification for the decision made. The second question of 384 questionnaires—covering all nine scenarios and both groups of students belonging to the first administration—was analysed to extract categories that represent students' views in a broad manner. The scenarios belonging to the second administration were then analysed using the categories generated through the previous analysis. In what follows, the number of questionnaires analysed per group and per scenario is shown. (In the case of the diet and diabetes scenario, the analysed questions were numbers 6 and 7, instead of question 2, see Appendix B).

Table 12 Number of questionnaires analysed per group and per scenario.

			Number of students		
Set	**Code**	**Scenario**	**Group 1**	**Group 2**	**Total**
1	WL	Weight-loss pills	19	19	38
	MP	Mobile phones	19	19	38
	SM	Self-medication	19	19	38
2	QM	Quantum medicine	22	25	47
	MH	Modified humans	22	25	47
	SK	Smoking	22	25	47
3	AD	AIDS denialists	27	16	43
	CC	Cloned cattle	27	16	43
	DD	Diet and diabetes	27	16	43
Total					384

The questionnaires for each scenario were analysed independently and categories were drawn through the constant comparative method (Lincoln and Guba, 1985). The categories initially generated were quite specific. Comparison of categories across scenarios allowed the generation of ever more general categories. At the end of the categorising process, nine categories and 15 subcategories—shown in Table 13—were derived.

Codes were assigned to each student for easy identification: The first numeral indicates the group, the second identifies the student and the letters after the forward slash signal the scenario. When the questionnaire was completed at the end of the course, the code is followed by an ‘f’. If the response was given during an interview, the code ends with ‘int’. For instance, the code 2.15/AD corresponds to student number 15 from group 2, who completed scenario about the Aids denialists (AD) at the beginning of the term.

Table 13 Categories and subcategories generated from the analysis of the scenarios

Category	Subcategory	Description	Exemplar quotes
Related to the NOS	Endorsed/rejected by research	The student claims that scientific research has demonstrated that certain procedure/knowledge is true or false. These claims are, however, not necessarily correct.	• No, because this association doesn't believe in science or in discoveries that corroborate that being HIV-positive causes AIDS (1.16/AD). • Up until now, this disease has killed a lot of people; mothers have transmitted the virus to their unborn babies. However, the association has no solid proof of what might happen. Besides, it has been demonstrated that when someone has the virus, he or she dies (1.33/AD). • Because it has been demonstrated that the nutrients it contains [food from cloned cattle] are good for one's health and that if animals reach maturity it is because they have good health (1.30/CC).
	Caution due to the lack of evidence	The student says his/her decision is influenced by the lack of scientific evidence.	• Because the questionings made about the effectiveness of this therapy are numerous, and I wouldn't dare to put my family at risk (1.29/QM). • Because there isn't enough evidence that says it works (1.59/QM). • Because you are playing with people's lives (not that other kinds of experiments don't) but in this case you modify organisms [genetically] and there are no proofs about possible side effects. So, if it is researched and it is concluded that there's no risk, then I would support it (1.15/MH).
	Appeal to authority	The student appeals to an authority without further justification for either trusting or not trusting.	• Our ignorance about the issue forces us to trust doctors (2.36/QM). • Because generally, the drug companies that make these kinds of products don't have the renown or reputation of others (2.27/WL). • Because one always must go to the doctor before taking any drug (1.41/SM).
	Scientists have political/economic interests	The student suggests that scientists have political or economic interests that affect their behaviour.	• If I knew they were cloned, I wouldn't eat them, because I feel that there are political or financial ends behind it. The scientists involved with it [the biotech industry] are the ones that give their approval while the other scientists are still unsure (1.26/CC).
	Disagreement among scientists	Student mentions the lack of consensus among scientists as a reason for his/her decision.	• Some say that there is no problem and other that there is. This causes a conflict (2.5/CC). • If I know they were cloned, I wouldn't eat them, because I feel that there are political or financial ends behind it. The scientists involved with it [the biotech industry] are the ones that give their approval while the other scientists are still unsure (1.26/CC).

Table 13 (cont). Categories and subcategories generated from the analysis of the scenarios.

Scientific knowledge	Justified scientific ideas	Student mentions scientific concepts and justify their use. These ideas can be correct or incorrect.	• Because sometimes they [weight-loss pills] can help, but on the long run the cause a metabolic imbalance in your body (2.48/WL). • It may be that the waves affect in some way the cells, just like the waves from the Sun affect the skin. Maybe mobile phones' waves cause some kind of problem (2.3/MP). • Because when it is said that an animal has been cloned, then they have the same properties, because they have the same genes. I don't think it's harmful (2.27/CC).
	Unjustified scientific ideas	Student mentions scientific concepts in a superficial manner. Their ideas can be correct or incorrect. They can also be clichés.	• Because sometimes one needs the will to heal, and if it comes from a placebo it's better (1.14/QM). • Because these kinds of vices [smoking] are very hard to control, and they also cause various diseases (2.31/SK). • As the text says, because of sound waves (1.63/MP). • Because an antibiotic is a powerful drug, and it seems he didn't have an infection (1.42/SM). • Because the human body can't take so many chemical substances; they have to be controlled and balanced (2.34/SM). • I exercise because I want a healthier life (1.40/DD).
More information is required		The student claims his or her decision is influenced by the ignorance about the situation at hand.	• Because, personally, I would need to know more about the treatment [quantum medicine], and also know about some arguments that could be corroborated (1.11/QM). • I would have to investigate the viewpoints of both sides, I mean, form my own opinion, without being influenced by any of the people involved and afterwards take one of the sides (2.8/QM). • Because she must first find out what kind of product she's buying and how was it made. She must check whether the active ingredients of the product are harmful (1.62/WL). • One should not self-medicate without knowing the disease one has (1.5/SM).

Table 13 (cont). Categories and subcategories generated from the analysis of the scenarios.

Trust in other sources	Confidence in others	The student claims that his or her decision is influenced by what non-scientists say about science or by its reputation and prestige.	• People that have taken it say that it cured them and there are no comments against it [quantum medicine]. If that is so, in spite of what the scientific community says, it doesn't matter, since patients have found a cure (1.9/QM). • Because the renown of Dr Nelson isn't due to his appearance, but to his knowledge (2.25/QM). • Because if they say that they know all the cases in-depth, or at least a large number of cases [of HIV], it could be said that the association has experience in the topic (1.31/AD).
	Lack of trust in others	The student claims that his or her decision is influenced by the lack of trust towards non-scientists. The student gives no reasons for why he or she mistrusts non-scientists.	• Because the majority of infomercials [about weight-loss pills] abuse merchandising and lie on order to sell (1.42/WL). • It is a particular case, so it doesn't guarantee the association is absolutely right. She should've continued investigating about the topic [HIV] (2.26/AD).
	Confidence in personal experience	The student claims that his or her decision is influenced by previous experiences, or that his or her decision depends on seeing with his or her own eyes the data.	• First I would have to see with my own eyes how it works [quantum medicine] and how people react to it, so I can make up my mind and pass judgment (1.38/QM). • Because my grandpa (God rest his soul) made a mistake I have no intention of repeating [smoking] (1.56/SK). • Because I don't know people that have suffered any harm using mobile phones (1.12/MP).

Table 13 (cont). Categories and subcategories generated from the analysis of the scenarios.

Ethical considerations	Personal beliefs	The student implicates his or her personal beliefs in his or her decision, whether religious or ethical.	• I wouldn't like it because it [the baby] would also contain genetic information from someone else, which I wouldn't really like. The best thing would be to adopt a child and avoid that (2.52/MH). • Manipulating human genes is not trivial; it's not something to play with, even if someone says that it can save lives. Genes are inherent to each person, it's what makes us unique, and mixing them with others is like stop being human (2.59/MH). • Because the procedure used to clone them [the cattle], obviously is not natural (2.55/CC).
	Individual freedom	The student justifies his/her decision on the basis of the freedom individuals have to make decisions.	• She's free to do what she thinks is right [about HIV treatment] (1.47/AD). • I think that whoever does it [accepting gene therapy] because he or she wants to, and also has full knowledge of the consequences, can make that decision (1.52/MH).
	Misuse of science	The decision is influenced by the notion that science is being misused or will be misused.	• There will always be a line between genetically-modifying an embryo to avoid a disease and doing this to make custom made genetically-modified embryos (1.46/MH). • Because this [gene therapy] is like a step in the search of human perfection and that's not healthy. Unfortunately, due to our natures, we have to complete a cycle and this stops the cycle from going on (2.8/MH).
Personal interests/preferences		The student justifies his or her decision by appeal to taste/well-being or distaste/lack of interest.	• Sometimes it [smoking] helps me to relax (1.44/SK). • Because I hate the smell of this product [cigarettes] (1.9/SK). • Because, simply, I'm not interested and I wonder what is it that smokers feel (2.32/SK).
Risk/benefit analysis		The student bases his/her decision in the comparison of the risk of a situation to its related benefits.	• Because I prefer to use drugs that are safe, rather than using the SCIO therapy that might not work (1.10/QM). • Because I don't think he [the patient] can get any worse (1.32/QM). • If somehow it's possible to avoid that a birth defect like Down syndrome, hermaphroditism, cardiac problems, et cetera, it [gene therapy] would improve his or her quality of life (1.11/MH).

Table 13 (cont). Categories and subcategories generated from the analysis of the scenarios.

Alternatives	Both options have something in their favour	The student sees both points of view as valid, and has trouble making a decision.	• Because, on the one hand, we have traditional medicine with a lot of years of experience, on the other, quantum medicine, that sounds pretty good (2.21/QM). • Because like all human beings, Maria hopes that the association's therapy will help her live longer, and even cure her. But, at the same time, the scientific community can provide her with that, and she also wants her baby to be healthy. If possible, I would consider using the best of both alternatives (2.39/AD).
	Helplessness/resignation	The student mentions that there is no control over the situation.	• I didn't decide it. It became addicted [to smoking] (1.46/SK). • Because when I bought it, I wouldn't know if the animals were cloned or not. You couldn't know which is which (1.65/CC).
Others		The student makes the decision based on practical matters. He or she mentions that the decision was based on aesthetical considerations, lack of time, economic factors. Intuition is also included in this category and it is when the students do not provide a clear or evident reason.	• Having a nice body, feeling good with myself—that motivates me to exercise (1.39/DD). • I don't exercise due to the lack of time and even dedication (2.25/DD). • Due to the cruel reality we live in, if we're realist, the majority of people has scant economic resources and thus cannot pay for expensive medicines (1.13/QM). • I don't understand the appeal of smoking, spending money on it and smelling bad (2.52/SK). • The vast majority of the products advertised in television don't seem to be reliable (1.12/WL). • I don't think they [mobile phones] can cause tumours (2.6/MP).

Students' responses to open questions were, in general, brief—making them fairly easy to categorise unequivocally. In the rare cases where responses could be placed in more than one category, the categorisation was discussed with another researcher and the response was reviewed in detail to determine, and justify, its place in one of the categories.

The categories presented in Table 13 cover the justifications given in all scenarios administered in the present study. In the following sections, the frequencies of use of each category in each scenario are shown and compared, both before and after the course. Categories are exemplified with a choice quote from the questionnaires.

5.1.3. Analysis of the relationship between students' decisions and their justification

Students used a broad range of justifications to support their decisions. These justifications were grouped, for all practical purposes, into those 1) relating to the NOS (endorsed/rejected by research, caution due to the lack of evidence, appeal to authority, scientists have political/economical interests, disagreement among scientists); 2) relating to scientific knowledge (justified and unjustified scientific ideas); and 3) relating to other factors (more information is required, trust in others, lack of trust in others, confidence in personal experience, personal beliefs, individual freedom, misuse of science, personal interest, risk/benefit analysis, analysis of both options, helplessness/resignation and other practical factors such as time and money) (For a full description see Table 13).

To examine if specific decisions were associated with certain justifications, responses (Yes/No/I don't know) were plotted against the type of justification given in each scenario (See below, figures 1-3). These graphs allow detecting and highlighting the role different ideas play in students' decisions, as well as comparing responses across scenarios.

5.1.4. Analysis of the changes of students' decisions at the beginning and at the end of the course

In order to determine the number of students that changed their decision and the direction of the change, responses before and after the course were compared for each student. The tables in the corresponding sections (see Tables 17-20 for pseudoscientific scenarios, Tables 24-27 for SSI scenarios and Tables 31-34 for well-established science scenarios) show the direction of the change, as well as in which category was the justification placed. Justifications are exemplified with choice quotes from the questionnaires. Likewise, changes in decisions are compared among different scenarios.

5.1.5. Analysis of the remaining questions of the DMQ

Besides asking students to justify their decisions, the DMQ included a series of questions designed to explore with more depth students' views about the particular topic. Specifically, students' ideas about scientists and other agents, the role of evidence, the mechanisms of action of the therapies and/or products, and their respective trustworthiness were all explored.

These questions were not used as a source of justifications of decisions, since they guided the student towards certain aspects of the scenarios that might not have played a role in his or her decision. However, these questions do offer the opportunity to know, with a little more depth, students' ideas about different aspects present in the scenarios.

The questions were designed and analysed in such a way as to allow comparisons among the different scenarios of each kind (that is, pseudoscientific, SSI, and well-established science) and to determine whether there are any differences in how students perceive the same factors when present in different scenarios.

5.1.6. Analysis of students' patterns of response

Each student completed three scenarios (one of each kind). In order to determine whether their responses to the three scenarios are consistent, and whether students can be classified according to their patterns of response across different scenarios, a two-step cluster analysis was performed with the aid of SPSS software. To perform the analysis, the categories extracted from students' body of justifications were used. Initially, since it has to be as wide as possible, the analysis compared the three kinds of scenarios, that is, pseudoscientific, SSI, and well-established science. However, justifications given in the well-established science scenarios were so different from those given in the other two types of scenarios that clusters did not form adequately: responses to the well-established scenarios defined cluster formation, masking or overpowering the responses to the other two kinds of scenarios. When pseudoscientific scenarios were analysed together with SSI ones, both kinds of scenarios contributed almost equally to cluster formation. As a consequence of this, the results of the analysis are more representative of the patterns present in the data. This is the reason why pseudoscientific and SSI scenarios were analysed together.

Finally, when analysing the responses given at the beginning and at the end of the course, no clusters were formed. Consequently, the analyses of responses from before and after the course were performed separately.

Cluster analyses described in this chapter are then:

- Pseudoscientific/SSI scenarios at the beginning of the course, and
- Pseudoscientific/SSI scenarios at the end of the course

5.2. Pseudoscientific scenarios

In contrast to SSI scenarios, which lack a correct and straightforward answer, pseudoscience scenarios do have a desired one that suggests that students can distinguish science from pseudoscience. This skill is a valuable one to have, since advertisements of these kinds of therapies and drugs seek to mislead consumers by couching their claims in what appears to be scientific language, supporting them with the testimony of people that apparently benefited from supposedly life-saving treatments. In spite of their shortness, all three pseudoscientific scenarios used in this study made it clear that scientists both disagree with the claims made in favour of the alternative medicine therapies and question their effectiveness. A brief explanation of the rationales offered by scientists against each of the treatments accompanied a description of the treatments themselves.

Students' degree of familiarity with the information presented in each of the three scenarios is variable. Miracle weight-loss pills and Aids are well-known to students. School science and the media provide ample, and for the most part trustworthy, information on the importance of a healthy diet and exercise in weight control and on the transmission of HIV. On the contrary, quantum medicine is a new and mostly unknown topic. Its medical mechanism of action is based on mistaken or inappropriately applied principles from quantum physics and a pseudoscientific concept—the so-called 'cellular frequency'. Students have little to no knowledge of advanced physics and medicine with which to judge the inefficacy of, and risks associated with, quantum medicine.

5.2.1. Students' decisions about pseudoscientific scenarios

The first question of the DMQ scenario asked students to make a decision about whether to accept or reject a pseudoscientific therapy. Table 14 presents these questions for each of the three pseudoscientific scenarios. The complete scenarios can be seen in Appendix B.

Table 14 Decision-making questions for the pseudoscientific scenarios.

Code	Scenario	Question
WL	Weight-loss pills	Would you recommend the pills to Carolina?
QM	Quantum medicine	Would you recommend this therapy to your relative?
AD	Aids denialists	Do you think Maria—after finding out she was HIV positive—should have followed the denialists' recommendations?

In what follows, students' responses to the decision-making question—both at the beginning and the end of the course—are presented, organised by scenario. To determine the change in the proportion of responses before and after the course, only those of students that completed the questionnaire twice were taken into account.

Table 15 Decisions of students for each scenario, before and after the course.

	Before			After		
	WL (n=29)	**QM** (n=35)	**AD** (n=29)	**WL** (n=29)	**QM** (n=35)	**AD** (n=29)
Yes	1 (.03)	15 (.43)	1 (.03)	0 (.00)	12 (.34)	2 (.07)
No	26 (.90)	7 (.20)	26 (.90)	29 (1.0)	12 (.34)	23 (.79)
I don't know	2 (.07)	13 (.37)	2 (.07)	0 (.00)	11 (.31)	4 (.14)

Frequency is shown in brackets.

Most students claimed not to make use of weight-loss pills advertised on television and to reject the anti-HIV therapies advocated by Aids denialists, both before and after the course. About these two topics few students exhibited uncertainty by selecting the 'I don't know' option.

A different picture emerges from responses to the quantum medicine scenario. At the beginning of the course, 43% of students claimed they would make use of a quantum medicine-based therapy, whereas only a third of students were unsure about whether or not to do so. At the end of the course, the proportion of students that rejected this therapy increased slightly, whereas the proportion of students that accepted it (or were unsure about it) decreased. Students' responses that changed after the course—as well as the direction of change—are explored in more detail below, together with their respective justifications.

5.2.2. Students' justifications to questions related to pseudoscientific scenarios

The following table shows the frequencies of each justification given by the students, both before and after the course, to each of the questions shown in Table 14. So as to have the broadest possible sample of justifications, for the present analysis all responses were taken into account, even those of students that did not complete the questionnaire twice. The categories used to classify the justifications are shown, in detail, in Table 13. Those categories not used by students when justifying their responses to pseudoscientific scenarios were omitted in for clarity of presentation.

Table 16 Number of instances of each category and subcategory for each scenario, before and after the course.

		Before			After		
Category	Subcategory	**WL** n=38	**QM** n=47	**AD** n=42	**WL** n=29	**QM** n=38	**AD** n=30
Related to the NOS	Endorsed/rejected by research	2 (.05)	1 (.02)	**11 (.26)**	2 (.07)	1 (.03)	**15 (.50)**
	Caution due to the lack of evidence	**11 (.29)**	**10 (.21)**	2 (.05)	**13 (.45)**	**12 (.31)**	1 (.03)
	Appeal to authority	1 (.03)	1 (.02)	**7 (.17)**	1 (.03)	2 (.05)	2 (.07)
Scientific knowledge	Justified scientific ideas	2 (.05)	0 (.00)	6 (.14)	0 (.00)	0 (.00)	0 (.00)
	Unjustified scientific ideas	1 (.03)	2 (.04)	2 (.05)	1 (.03)	0 (.00)	1 (.03)
More information is required		6 (.16)	5 (.11)	1 (.02)	0 (.00)	2 (.05)	0 (.00)
Trust in other sources	Confidence in others	1 (.03)	3 (.06)	4 (.10)	0 (.00)	1 (.03)	2 (.07)
	Lack of trust in others	**9 (.24)**	1 (.02)	2 (.05)	**11 (.38)**	2 (.05)	5 (.17)
	Confidence in personal experience	0 (.00)	2 (.04)	0 (.00)	0 (.00)	0 (.00)	0 (.00)
Ethical considerations	Individual freedom	0 (.00)	0 (.00)	4 (.10)	0 (.00)	0 (.00)	3 (.10)
Personal interests/preferences		0 (.00)	1 (.02)	0 (.00)	0 (.00)	0 (.00)	0 (.00)
Risk/benefit analysis		5 (.13)	**12 (.26)**	2 (.05)	1 (.03)	**15 (.39)**	0 (.00)
Alternatives	Both options have something in their favour	0 (.00)	2 (.04)	1 (.02)	0 (.00)	0 (.00)	1 (.03)
Others		0 (.00)	7 (.15)	0 (.00)	0 (.00)	3 (.08)	0 (.00)

In brackets are shown the student frequencies for each case.
In bold are shown the highest proportions for each scenario.

There are differences among scenarios in the types of justifications offered by students when making a decision. At the beginning of the course, on the weight-loss pills scenario students justified their decisions by making reference to the lack of trust engendered by the makers and sellers of the product and the lack of evidence. The most commonly used strategies in this scenario did not change after the course:

> The vast majority of these products are fake and we have no real evidence to guarantee that they work (1.19/WL).
>
> Don't trust everything that appears in advertisements—they just want to sell you things (1.63/WLf).

In the quantum medicine scenario, both at the beginning and the end of the course, the two most used justifications were caution due to the lack of evidence and risk/benefit analysis:

> Because it seems that it's still in an experimental phase (2.23/QM).
>
> [E]verything must be tried to [improve] a relative's health. If the only way, I mean, the only treatment, is unsuccessful or partially successful, you have to try other ways (2.22/QMf).

In the Aids denialists scenario, students were concerned with whether the pseudoscientific claims were endorsed or rejected by scientific research. Alternatively, students appealed, to base their decisions, to scientific authority and, to a lesser degree, to justified scientific ideas. In this case, at the end of the course students appealed less to scientific authority and slightly more to the lack of trust aroused by the denialist organisation.

> Because numerous studies (as far as I know) have shown that the use of antiretroviral drugs improved the quality of life of people with HIV (1.18/AD).
>
> Because what the doctor says is more reliable (1.27/AD).
>
> The reasons given by the Asociación Monarcas are unfounded, and it is clear that a good diet does not affect the fight against the virus (2.29/AD).

At the beginning of the course, both in the weight-loss pills and in the quantum medicine scenarios, students made frequent references to the importance of having information. In the first scenario, some students argued that Carolina herself would need to seek better information. In the second, many demanded more information before making a decision:

> I think that I should first do some research about the treatment, find out about others' cases and objectively analyse each option (considering pros and cons) (1.15/QM).

At the end of the course, the demands for information decreased in all scenarios.

Contrary to what happened with the weight-loss pills and the Aids denialists scenarios, several students couched their decision about quantum medicine on other—more pragmatic—factors, such as economic reasons:

> Due to the cruel reality we live in, if we're realist, the majority of people has scant economic resources and thus cannot pay for expensive medicines (1.13/QM).

The difference in the number of appeals to authority in the weight-loss and quantum medicine scenarios compared with the Aids-denialists scenario is striking. All scenarios explicitly state that scientists disagree with the therapies proposed by Dr Nelson, the Asociación Monarcas, and the pills makers. However, students seemed not to consider the credibility of scientists a useful criterion in the case of quantum medicine and weigh-loss pills.

The same thing happened with the category 'endorsed/rejected by research'. In spite of the fact that the texts mention that scientists are opposed to those kinds of therapies, in the case of the Aids-denialists students used this argument much more frequently than in the case of quantum medicine and weight-loss pills.

Another justification used only in the case of Aids denialists was an appeal to the freedom that each individual has to do whatever he or she thinks is more convenient. Even though all scenarios invited students to judge the decision of someone else towards the therapy, only in the Aids denialists scenario did students claim that Maria was free to do as she wished.

In the weight-loss pills scenario, students tended to mistrust the companies that sell these products, although no one expressed the same mistrust of people that practice quantum medicine and only two students expressed mistrust towards the Asociación Monarcas.

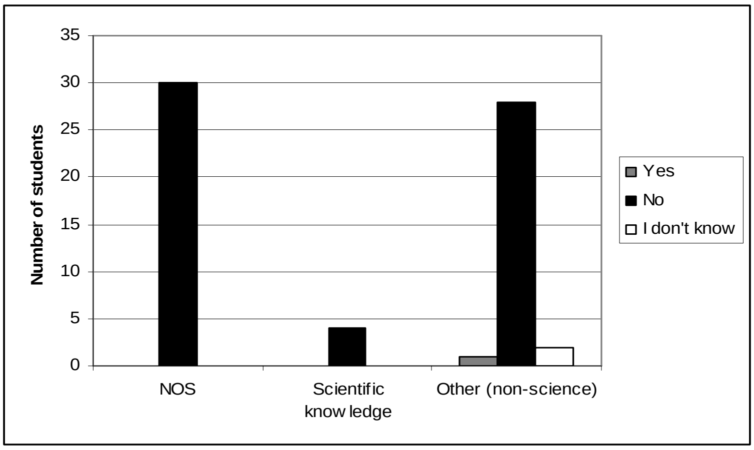
Even though the three scenarios contained scientific information, the little use in decision-making of scientific ideas on the part of students was noticeable, both of the justified and unjustified kinds. However, the fact that students made reference to whether a given therapy is accepted or rejected by scientific research usually means they know something about it.

Given the above findings, it is apparent that familiarity with the topic influences the way students justify their decisions. When students know something about the topic, such as Aids and diet, they resorted more to ideas of and about science, including the role of evidence, the importance of being endorsed by research, and the reliability of scientists. On the contrary, when students are not familiar with the topic, or the scientific content knowledge involved, such as in the case of quantum medicine, they made their decisions on the basis of non-scientific criteria, such as risk/benefit analysis, and caution due to lack of evidence. In this case, in spite of the fact that the scenarios clearly established that scientists do not endorse these examples of alternative medicine, many students seemed not to take into account the role of research or the trustworthiness of scientists.

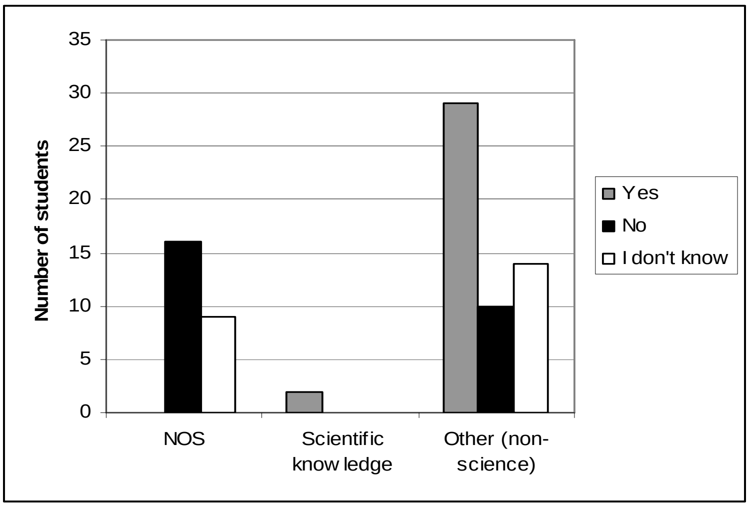
5.2.3. Students' decisions and their relationship to their justification

Up until now it has been evident that students justify their decisions with arguments related to the nature of science (with more or less sophisticated views), based on their scientific knowledge (which might be right or wrong or inappropriately applied) and appealing to non-scientific factors, such as risk/benefit analysis, practical, or ethical considerations. These findings invite the question of whether students that used their ideas about the NOS or their scientific knowledge to justify their decisions were more likely to reject pseudoscience than those students that relied on other criteria. To find an answer, three types of justification (NOS, scientific knowledge, and non-scientific considerations) were compared with the number of students that answered Yes/No/I don't know in each of the three pseudoscience scenarios. In the following figures, data from before and after were conflated for each scenario.

A



B



C

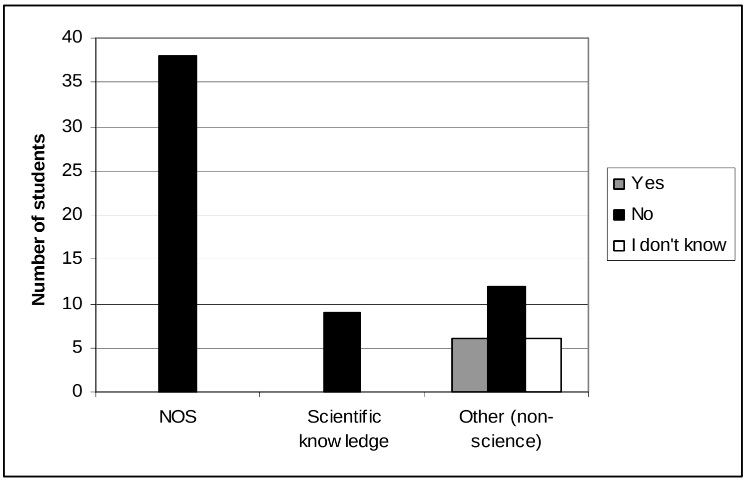


Figure 1 Number of students that answered Yes/No/I don't know grouped according to category of justification. Box A: weight-loss pills scenario; Box B: quantum medicine scenario; Box C: Aids denialists scenario.

Note: The category NOS includes, as mentioned in Table 13, the endorsement/rejection by scientific research, caution due to the lack of evidence, and appeal to scientific authority. Scientific knowledge includes justified and unjustified scientific ideas. Non-scientific factors comprise trust or distrust in non-scientific sources, ethical considerations, personal interest, risk/benefit analysis, consideration of diverse alternatives, and practical considerations.

Students that used as justification an idea of the NOS did not accept the proposed therapies in any of the three scenarios. In the case of quantum medicine (Figure 1, Box B) some students that used ideas of the NOS as justification were indecisive. In the case of scientific knowledge, its association with rejection of quantum medicine is not that clear (Figure 1, Box B). This might be due to the fact that some students used scientific ideas incorrectly, especially about the placebo effect, when making a decision.

> Because sometimes will is needed to heal, and if [healing] is caused by a placebo effect it's better (1.14/QM).

> If they get cured because of the placebo effect it wouldn't be wrong for her to heal herself (1.64/QM).

Students' responses when justifying their decisions by recourse to non-scientific ideas were more varied. In the case of the weight-loss pills (Figure 1, Box A), the majority of students that claimed not to be willing to take them expressed distrust towards the companies that manufacture them. From students' responses it was not possible to determine the cause of the lack of trust, which could be the product of scientific knowledge, ideas of the NOS, or the bad reputation of these companies.

> All media, to sell, invent and even deceive people with exaggerated arguments (2.42/WLf).

In the case of quantum medicine (Figure 1, Box B), almost all students that claimed that they would be willing to subject themselves to the therapy used non-scientific factors to make their decisions, mainly risk/benefit analysis:

> Because finally her life's in danger one way or another, and if she can be cured with the resonance, well then, nothing is lost by trying (2.143/QM).

Finally, in the case of the Aids denialists, all students that said that they would recommend the Asociación Monarcas fall squarely into this category: they argued mainly using ethical considerations of freedom of individual choice:

> Well, it's her decision. Being optimistic, the decision she makes will be for her benefit and that of her child (2.37/AD).

These findings suggest that ideas of the NOS can be useful guidelines for students to make informed decisions about pseudoscientific issues, whether or not they are familiar with the issue. No student that relied on ideas of the NOS accepted the therapies. The quantum medicine (Figure 1, Box B) scenario was the least familiar to students and, because of this, some students could not make a decision one way or another, even though they used ideas of the NOS. This could be construed as a positive advance, at least compared with other less critical justifications that led students to trust the therapies blindly, since there is nothing to lose.

5.2.4. Changes in students' decisions to pseudoscientific scenarios after the course

As seen in Section 5.2.1, the proportions of students that chose each answer did not vary much before and after the course. However, there were some students that did change their minds. These changes are shown in Table 17.

Table 17 Numbers and frequencies of students that changed their decisions according to pseudoscientific scenario.

	WL	QM	AD
	n=29	n=35	n=29
I don't know→No	2	4	1
I don't know→Yes	0	1	0
No→ Yes	0	0	1
No→ I don't know	0	2	3
Yes→ No	1	3	0
Yes→ I don't know	0	1	0
Total changes	3	11	5
Frequency	0.1	0.31	0.17

WL: Weight-loss pills; QM: Quantum medicine; AD: Aids denialists.

A minority of students changed their mind (19 of 93), with different proportions in each scenario. In what follows, these changes are explored in detail, particularly with the aim of determining if these changes are related with variations on the justifications offered.

5.2.4.1. Decision changes in the weight-loss pills scenario

In total, three students changed their decision in this scenario. In the three cases, the decision at the end of the course was rejection of weight-loss pills and the justifications changed from non-scientific to those related to scientific ideas or the NOS. These changes are shown in Table 18.

Table 18 Decision changes and justifications used in the weight-loss scenario.

Number of students	Category of the initial justification	Category of the final justification	Example
I don't know → No			
1	Risk/Benefit analysis	Unjustified scientific ideas	*Initial*: The product might not work just as it's said on TV, but it might help somehow (2.03/WL). *Final*: [T]hese are products about which you can't really know what their effect will be on the body (2.03/WLf).
1	Confidence in others	Precaution due to the lack of evidence	
Yes → No			
1	More information is required	Endorsed/rejected by research	*Initial*: I would recommend it, but with the necessary information that one needs to have and not just buying it for buying's sake. Maybe someone could find a product that does work. Besides, technology could help us but not substitute other things (2.34/WL). *Final*: Because it doesn't have the endorsement of doctors (2.34/WLf).

5.2.4.2. Decision changes in the quantum medicine scenario

This scenario was the one where more students changed their decisions—almost a third. Of the eleven students, seven changed their decision about whether to use quantum medicine to 'No', three to 'I don't know', and one to 'Yes'.

Table 19 Decision changes of students and justifications used in the quantum medicine therapies scenario.

Number of students	Category of the initial justification	Category of the final justification	Example
I don't know → No			
2	Precaution due to the lack of evidence	Precaution due to the lack of evidence	*Initial*: Because there still haven't been stringent investigations that confirm the effectiveness of the therapy—I don't trust it fully (2.59/QM). *Final*: Because there're no stringent studies about its effectiveness (2.59/QMf).
1	More information is required	Appeal to authority	
1	Both options have something in their favour	Precaution due to the lack of evidence	
Yes → No			
2	Risk/Benefit analysis	Precaution due to the lack of evidence	*Initial*: Because it's a new opportunity that may change both his and his family's life, and maybe doctors can't guarantee the same life expectancy (2.46/QM). *Final*: I think that it would be too risky, because we don't know exactly if it works or not (2.46/QMf).
1	Confidence in others	Precaution due to the lack of evidence	
No → I don't know			
1	Endorsed/rejected by research	Risk/Benefit analysis	*Initial*: I think that in many occasions science is right, but it can make mistakes—however, the placebo effect is quite common and is capable of leading to confusions (1.1/QM). *Final*: Because there have been many speculations that don't reflect positively on the treatment, but also it's good to try scientific advances to see if they benefit society (1.1/QM).
1	Lack of trust in others	NA*	
Yes → I don't know			
1	Risk/Benefit analysis	Precaution due to the lack of evidence	*Initial*: Before starting with a medical treatment, I would suggest trying the alternative to test its effectiveness without drugs, and then on that basis continue it or change to drugs (2.35/QM). *Final*: A life is endangered if its put in the hands of a not fully tested treatment (2,35/QM).
I don't know → Yes			
1	Precaution due to the lack of evidence	Others	*Initial*: Because I don't know if the results of this therapy are real or if it would be a loss of time and money that would be better spent elsewhere (2.38/QM). *Final*: Because it's a good option and very cheap for someone to be cured (2.38/QM).

*NA was used when the student didn't answer the open question, answered 'I don't know', or his/her answer was unclassifiable within the existing categories.

The seven students that changed their decisions to ‘No’ used, ultimately, justifications related to the NOS. The three students that changed from a definite position (‘Yes’ or ‘No’) to an undecided one also changed their justifications with no clear trend. One student initially rejected the therapy, offering the ‘Endorsed/rejected by research’ criterion, but changed to an indecisive position justified by reference to a risk/benefit analysis. Another student went from accepting the therapy, justifying it through a risk/benefit analysis, to an indecisive position justified through lack of evidence. The third student’s response proved to be unclassifiable. The only student that changed his or her decision and ended up accepting the therapy went from precaution due to lack of evidence to other non-scientific factors, specifically economic ones.

Apparently, using ideas of the NOS as a justification for a decision is associated with the rejection or uncertainty towards these kinds of therapies, whereas other factors, such as risk/benefit analysis, the (blind) trust in others, and practical considerations lead to more varied decisions.

5.2.4.3. Decision changes in the Aids denialists scenario

In total, five students changed their decisions in this scenario.

Table 20 Decision changes and justifications used in the Aids denialists scenario.

Number of students	Category of the initial justification	Category of the final justification	Example
No → I don't know			
1	Endorsed/rejected by research	Individual freedom	*Initial*: The medical recommendations are intended to save her life (2.30/AD). *Final*: She can decide about the treatment to follow; finally, it's her life (2.30/ADf).
1	Lack of trust in others	NA*	
1	Appeal to authority	Individual freedom	
I don't know → No			
1	Individual freedom	Endorsed/rejected by research	*Initial*: Well, that's her decision. Being optimistic, whatever she decides will benefit her and her child (2.37/AD). *Final*: That is not something scientific—it only provides hope (2.37/ADf).
No → Yes			
1	Justified scientific ideas	Confidence in others	*Initial*: Having a healthy diet must be followed always. Otherwise, we would all be sick the way we live, yes? (2.41/AD). *Final*: Because it's simple the right thing, because the organisation knows the problem in-depth (2.41/ADf).

Two of the students that changed their decision from 'No' to an indecisive position did so by saying that each person has the right to decide for themselves. On the contrary, the student that went from an indecisive to 'No' changed his justification from an appeal to individual freedom to an appeal to the results of scientific research about HIV. Finally, the student that changed his position from 'No' to 'Yes' initially used his knowledge about science, but at the end expressed blind confidence in the association.

5.2.5. Students' responses to the remaining questions of the questionnaires

The remaining questions of the questionnaires about pseudoscience aimed to clarify students' views of the treatments and the mechanisms of action of the therapies or products, of the individuals or associations that advertise them, and of scientists' criticisms in each case. These responses were not taken into account as justifications of decisions, since they were targeted towards students' ideas about specific topics that might or might not have influenced their decisions.

5.2.5.1. Students' views of the treatments and/or the mechanisms of action of the products in the pseudoscientific scenarios

When asked about their views on the mechanism of action of the weight-loss pills, almost half of students thought it was false. Some even justified their response by pointing out the errors in the mechanism of action. Scientific information offered by students, however, was not necessarily correct:

> I'm not convinced. It says that when cells perceive the linoleic acid their function changes—that's not normal (1.21/WL).

A fifth part of students said that the mechanism of action is correct but it has been exaggerated. Another fifth of students mentioned that the advertisers of the product use, on purpose, complicated and impressive terms that are not understandable so that people trust them. These students did not clarify if they thought the mechanism is correct.

> [They] use scientific terms that the majority of people are unfamiliar with—that's why they buy them (1.42/WL).

A different picture emerges in the quantum medicine scenario. In it, several students (19 of 46) were uncritical, arguing that the mechanism seemed coherent and was similar to concepts they had heard. Alternatively, they felt that if the manufacturers claimed it worked it must be true.

> I think that it's logical because, ultimately, our body works, partly, through electric charges—like in electroshocks (2.22/QM).
>
> It's a good treatment, even if there is no evidence that it actually works (2.38/QMf).

A minority of students (9 of 46) said that the arguments are not convincing and appear to be false, given the strong financial interest of the therapists. Fourteen students claimed that there is a possibility that the therapy might work, but at present there is not enough of the necessary information to make a decision:

> If they say their testimonies are real, maybe they're right. But they should make an in-depth investigation to see if it's really the device that's curing people (1.53/QMf).

In the case of the Aids denialists scenario, many students were sceptical of the therapy. 28 students (out of 40) thought the treatment advocated by the association had no grounds and was risky and untrustworthy. Nine students claimed that the treatment advocated by the association (consisting of a healthy diet and low stress) helps the work of antiretroviral drugs.

> [The treatment] undoubtedly helps to improve the quality of life, but it's not enough to counteract the effects of HIV. This treatment would only be a complement to antiretroviral drugs (1.18/AD).

These views suggest that the amount of knowledge students have about a topic influences how they evaluate apparently scientific arguments given by different agents. When students have more knowledge of a topic, as is the case of Aids and the weight-loss pills, they tend to reject pseudoscientific arguments. However, when the topic is less familiar, as is the case of quantum medicine, students are more willing to believe arguments that use scientific language, in spite of the fact that the scenario made it clear that scientists do not agree with the supposed mechanism of action and an alternative scientific explanation was offered. These findings echo the decisions made by students when faced with the different scenarios: in those where rejection predominated (Aids-denialists and weight-loss pills), more students criticised the mechanism of action or the therapies themselves; in those where acceptance predominated (quantum-medicine), students were more uncritical, or willing to trust, the arguments of the advocates of the therapy.

5.2.5.2. Students' views concerning the position of doctors and scientists

In the weight-loss pills scenario, the majority of the students (23 out of 37) willing to use weight-loss products used as a decision-making criterion the advice of a doctor, which suggests that they had some measure of confidence in doctors.

The attitude towards doctors and scientists in the case of quantum medicine was more negative. Only twelve students out of 43 believed that scientists and doctors have grounds for criticising quantum therapies. Eight students commented that scientists do not accept these kinds of therapies because they are close-minded and follow only their traditional methods. Several students (8 out of 43) think that both positions could be true, and four students mentioned that doctors criticise the therapy because they are afraid of competition. Some students commented that scientists and doctors argue against the therapy because they are not familiar with it and, consequently, should subject it to tests to show why they are against it:

> [Scientists] are good, they know what they're talking about—but I think they're wrong (2.21/QM).
>
> [Scientists' arguments] are coherent but insufficient, since they only have the hypothesis of why it works. But they should determine if it really works with sick patients (2.52/QMf).
>
> [Scientists' arguments] are the most rational and reasonable. They have experience, knowledge, and possess diverse interests that wouldn't make them join together for such an unethical and incredible reason. You have to remember that science develops and improves through experimentation, refutations, and the acceptance of hypotheses (2.56/QMf).

Several students believed that scientists and doctors should only be allowed to criticise the therapy if they had already tested it themselves (14 out of 47). However, no students mentioned that this therapy contradicts modern medical theories or ideas. Those that opposed the criticisms from scientists claimed that scientists are close-minded, traditionalists, afraid of competition, and have personal interests that, together, are the source of their criticism of quantum medicine.

In the case of the Aids denialists, students tended to lend some credence to scientists: 37 out of 41 students claimed that scientists have enough grounds for criticising the therapy advocated by the Aids denialists. Students argued that scientists have the knowledge of, or have studied, the virus and the disease. Only one student commented that scientists do not have enough evidence to back their arguments.

> They [scientists] only support the results of their research—they would like it if what the association says was true, but experiments say otherwise (1.26/AD).

In this case, it appears that the familiarity of students with the topic influenced their degree of confidence towards scientists. When the topic is unknown to them (such as quantum medicine) and scientists criticise it with arguments, students think that scientists are close-minded, ignorant, or overzealous of their personal interests. On the contrary, when students know about the topic (weigh-loss and Aids denialists), they tend to agree with the position of scientists.

5.2.5.3. Students' opinion concerning the advocates of alternative therapies and drugs

Almost all students believed that weight-loss pills advertisements call upon the slogan 'scientifically proven' to lend some credibility to products, and that, for the most part, advertisements lie. A few students believed that the product was indeed subjected to tests; two of them commented that maybe some tests were done, but not necessarily with human subjects.

> Because maybe it has been tested in animals but not in people (1.42/WLf).

In the quantum medicine scenario, more than half the students agreed with claims made by the inventor of the therapy: criticisms against quantum medicine are the result of the personal interest of doctors and the economic interests of pharmaceutical companies. Only five students (out of 47) called to task the inventor of the therapy, asking of him better, more solid arguments instead of criticisms of the medical and pharmaceutical profession. Four students conceded that the inventor of the therapy also has personal interests at stake that could account for his criticisms of doctors and scientists.

> Well, hoping to profit from the therapy, he [the inventor], like doctors and scientists, will look for the way to argue against his rivals (1.11/QM).
>
> I've seen several TV documentaries about drugs, I mean, pharmaceutical companies are not interested in the well-being of people, I mean, it could be said that scientists are interested in the well-being of people, but pharmaceutical companies are only interested in… For example, a new disease appears and a drug is devised to cure it. For [pharmaceutical companies] don't care

> whether the drug cures the disease, whether it has side effects—
> what they want is to sell. To sell and sell (1.32/QM*int*).

In the scenario of the Aids denialists, the majority of students (30 out of 42) thought that the Asociación Monarcas has no grounds with which to defend its stance, since it has conducted no research and contradicts existing evidence. Two students believed that its position is close-minded. Five students were willing to give the benefit of the doubt to the association.

> Well, they [the association] don't have 'conclusive' grounds to say
> that their treatment works while the other is harmful (2.57/AD).

As expected, given the responses to the two subsections above, in this case trust in the advocates of the therapies and the drugs apparently depends, directly, on students' degree of familiarity with the topic and, inversely, on their ideas about scientists. That is, when faced with familiar scenarios (Aids denialists and weight-loss pills) many students reject the advocates. On the contrary, many students are more willing to accept and agree with advocates of quantum medicine.

5.3. SSI scenarios

SSI scenarios, unlike pseudoscientific ones, do not have a single correct answer. The topics they cover are many-sided; disagreement among scientists and lack of evidence are just one of many sources of uncertainty. The SSI scenarios devised for the present study are characterised by students' varying degrees of familiarity with them, by the implications or consequences of the decisions made about them, and by the types and depth of the scientific knowledge needed to solve them.

5.3.1. Students' decisions about SSI scenarios

The first question of the SSI scenarios asked students to make a decision about the stated controversy. These questions can be seen in Table 21. The complete scenarios can be found in Appendix B.

Table 21 Decision-making questions for the different SSI scenarios.

Code	Scenario	Question
MP	Mobile phones	Do you think that mobile phones can be harmful?
MH	Modified humans	Do you agree with the genetic modification of embryos in order to prevent an illness?
CC	Cloned cattle	Would you eat or drink meat or milk from cloned cattle?

The following table (Table 22) summarises students' decisions for each of the three scenarios. With the aim of determining the changes in the frequencies of responses before and after the course, only responses from students that completed the same questionnaire at the beginning and at the end of the course were subjected to analysis.

Table 22 Students' responses to the SSI scenarios before and after the course

	Before			**After**		
	MP (n=29)	**MH** (n=35)	**CC** (n=29)	**MP** (n=29)	**MH** (n=35)	**CC** (n=29)
Yes	7	13	15	7	15	12
No	4	16	6	5	17	7
I don't know	18	6	8	17	3	9
Non-response	0	0	0	0	0	1

As can be seen from Table 22, there were differences in the responses to each of the scenarios. In the mobile phone scenario, all students showed a high degree of uncertainty about whether mobile phone use is harmful or safe. On the contrary, responses for the modified humans scenarios were more clear-cut (that is, more students answered either 'yes' or 'no' while fewer students claimed not to know what to answer). These frequencies did not vary that much at the end of the course. In the cloned cattle scenario, positive responses predominated slightly over negative ones: students proved to be more willing to eat foodstuffs from cloned animals, both before and after the course. In the case of this scenario, the number of indecisive students was lower than that of students that responded positively and higher than that of students that responded negatively.

5.3.2. Students' justifications of their answers to SSI scenarios

The second question of the questionnaire asked students to justify their decision. In the following table (Table 23), the frequencies of each justification given by students are summarised. In this particular case, justifications from all questionnaires (not just those completed both at the beginning and at the end of the course) were taken into account, so as to build the largest possible collection of justifications. Categories are described in Table 13. Categories not mentioned by students were omitted from Table 23 for the sake of clarity.

Table 23 Number of instances of each category and subcategory for each scenario, before and after the course.

		Before			After		
Category	**Subcategory**	**MP** n=38	**MH** n=43	**CC** n=41	**MP** n=27	**MH** n=41	**CC** n=28
Related to the NOS	Endorsed/rejected by research	1 (.03)	0 (.00)	5 (.12)	1 (.04)	0 (.00)	4 (.14)
	Caution due to the lack of evidence	**15** (.42)	**17** (.40)	**10** (.24)	**9** (.33)	**14** (.34)	**9** (.32)
	Scientists have political/economic interests	0 (.00)	0 (.00)	1 (.02)	0 (.00)	0 (.00)	1 (.04)
	Disagreement among scientists	0 (.00)	0 (.00)	1 (.02)	1 (.04)	0 (.00)	0 (.00)
Scientific knowledge	Justified scientific ideas	**8** (.21)	0 (.00)	**11** (.27)	3 (.11)	2 (.05)	1 (.04)
	Unjustified scientific ideas	2 (.05)	0 (.00)	0 (.02)	7 (.26)	0 (.00)	**7** (.25)
More information is required		2 (.05)	0 (.00)	5 (.10)	1 (.04)	0 (.00)	2 (.07)
Trust in other sources	Confidence in personal experience	7 (.18)	0 (.00)	1 (.02)	**5** (.19)	0 (.00)	0 (.00)
Ethical considerations	Personal beliefs	0 (.00)	3 (.07)	2 (.05)	0 (.00)	5 (.12)	0 (.00)
	Individual freedom	0 (.00)	1 (.02)	0 (.00)	0 (.00)	1 (.02)	0 (.00)
	Misuse of science	0 (.00)	4	0 (.00)	0 (.00)	1 (.02)	0 (.00)
Risk/benefit analysis		2 (.03)	**18** (.42)	2 (.05)	0 (.00)	**17** (.41)	4 (.14)
Alternatives	Both options have something in their favour	0 (.00)	0 (.00)	0 (.00)	0 (.00)	1 (.02)	0 (.00)
	Helplessness/resignation	0 (.00)	0 (.00)	2 (.05)	0 (.00)	0 (.00)	0 (.00)
Others		1 (.03)	0 (.00)	1 (.02)	0 (.00)	0 (.00)	0 (.00)

Frequencies of responses are shown between brackets.
The highest frequencies are shown in bold.

In all three scenarios, a high proportion of students, no matter what their decision, made a cautious decision given the lack of evidence, both before and after the course:

> Because we don't yet have enough evidence to prove they are harmful (1.17/MP).
>
> It may be good because it helps when it's needed, but no one knows the effects they could have in a few years or in a few generations (1.32/MH).

Risk/benefit analysis was the most widely used argument to justify their decisions about the modified humans scenario. Several students justified their decision saying that genetically modifying humans would be a big scientific advance. They also relied on the notion that science exists for the benefit of humankind or to alleviate human suffering.

> Prevention of these inherited diseases would be a breakthrough that would benefit all mankind. Experimenting is the only way to achieve this (2.35/MH).
>
> Because the rate of diseases would drop and the babies born with these characteristics could have a better quality of life (2.13/MH).

On the contrary, this type of analysis was not so important for students making a decision about the harm caused by mobile phones and the use of products from cloned cattle.

Ethical considerations had more weight in the modified humans scenario, than in the remaining two SSI scenarios, both before and after the course: students made reference to both their personal beliefs and the misuse of scientific discoveries:

> Manipulating human genes is not trivial; it's not something to play with, even if someone says that it can save lives. Genes are inherent to each person, it's what makes us unique, and mixing them with others is like stop being human (2.59/MH).

Several students relied on both some justified scientific ideas—in a higher proportion—and some unjustified ones in the mobile phones and the cloned cattle scenarios. However, in the scenario about modified humans, no student mentioned any scientific ideas.

> Because microwaves might actually alter cell components, but since no effect has been found in people, we cannot say that they are harmful (2.10/MP).

At the end of the course the frequency of use of justified scientific ideas decreased in both scenarios, whereas the frequency of use of unjustified scientific ideas increased. In the scenario about genetically-modified humans, use of justified scientific ideas increased slightly at the end of the course.

Students relied more on their personal experience when making decisions about mobile phones, compared with the other two SSI scenarios both at the beginning and at the end of the course:

> I've never seen an illness caused by a mobile phone (1.41/MP).

Disagreement among scientists, a common aspect of SSI, was only considered to be important for decision-making by two students; one in the cloned-cattle scenario (at the beginning of the course) and the one in the mobile phone scenario (at the end of the course).

> Some say that there is no problem and other that there is. This causes a conflict (2.5/CC).

Finally, two students felt that they had no power over whether or not to eat products from cloned cattle—they believed they wouldn't know if they ate it. This impotence towards decision-making was not expressed in any other SSI scenarios.

> Because when I bought it, I wouldn't know if the animals were cloned or not. You couldn't know which is which (1.65/CC).

In summary, in the case of SSI scenarios the most commonly used justification was caution due to lack of evidence. However, differences in the remaining kinds of justifications used were detected among scenarios. In the mobile phones scenario, the closest to students' everyday experience, justified scientific ideas and personal experience were also frequently used justifications. These kinds of scientific ideas were also used in the case of the cloned cattle, but not in the case of genetically-modified humans, where risk/benefit analysis played a bigger role (even though students failed to take into account the full range of relevant factors included in the scenario in analysis of possible risks and benefits). In the case of cloned cattle, endorsement/rejection from existing research was an idea commonly used by several students in order to justify their decision.

5.3.3. Students' decisions and their relationship with their respective justifications

So far, the results of the study suggest that there are differences among scenarios in how students respond. Generally-speaking, many students relied on both caution due to lack of evidence and the endorsement or rejection by scientific research to make their decisions (both arguments belong to the NOS category and are detailed on Table 13). Students also relied on their ideas about scientific concepts and other factors unrelated to science—such as risk/benefit analysis and ethical and practical considerations—to make a decision about the different scenarios.

Is there any relationship between students' decisions and the kinds of justifications used? To find this out, students' decisions were plotted in three groups, each group corresponding to a different kind of justification: those related to the NOS, to scientific ideas, and to other, non-scientific, ideas (i.e., the request for more information, ethical considerations, and risk/benefit analysis and other practical considerations; for a detailed description, see Table 13).

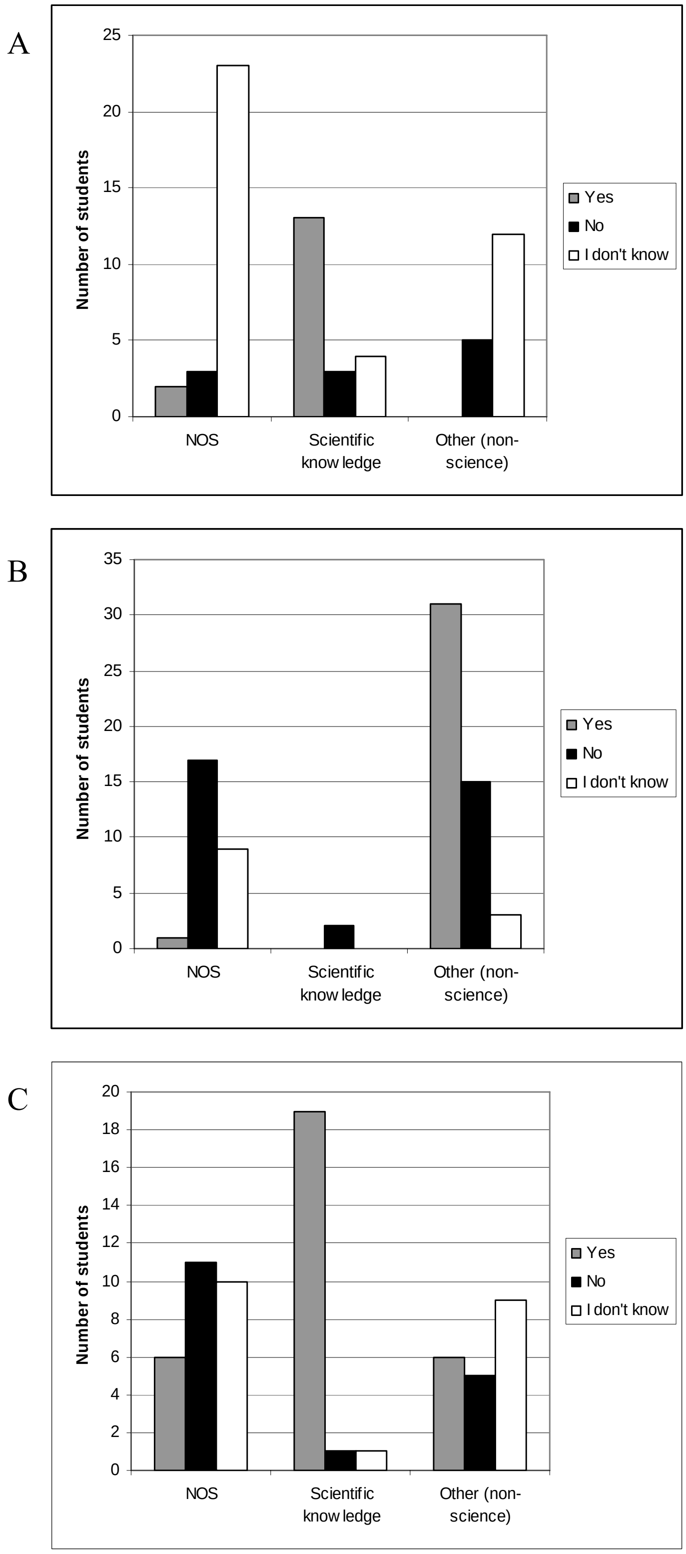


Figure 2 Number of students that answered Yes/No/I don't know, grouped according to the kind of justification used to make the decision. Box A: mobile phones scenario; Box B: genetically-modified humans scenario; Box C: cloned cattle scenario.

Concerning the decisions made (Yes/No/I don't know), there are notable differences among the scenarios in the frequency of the use of ideas related to the NOS, scientific ideas, and other decision factors. These differences will be detailed in the following subsections.

a) Criteria related to the NOS

As mentioned earlier, in the mobile phones scenario (Figure 2, Box A), the majority of students showed a measure of uncertainty in their decisions by answering 'I don't know'. The majority of these indecisive students used criteria related to the NOS (especially, caution due to the lack of evidence).

> Because harmful effects haven't been proven, but that doesn't mean that those kinds of effects could appear in the long term (1.66/MP).

In the case of the genetically-modified humans (Figure 2, Box B), the majority of students that used criteria related to the NOS (mainly, caution due to lack of evidence) answered that they were against genetic engineering being applied to humans for medical purposes. Next were students that answered 'I don't know'.

> Genetic diseases haven't been properly understood. Before attempting to cure them, they should first be understood (1.64/MH).

Finally, in the case of cloned cattle (Figure 2, Box C), the majority of students that used criteria related to the NOS to justify their decision either did not agree with the consumption of foodstuffs from cloned animals or showed uncertainty on the matter. These students appealed mainly to caution due to the lack of evidence. However, six students that expressed a willingness to consume these types of foodstuffs, and most of them argued that they would do so because these products have the endorsement of scientific research (in spite of the fact that the scenario made reference to the controversy surrounding the issue).

> Because it has been proven that the nutrients contained by these foodstuffs are good for people's health, and if animals reach adulthood that means that they themselves have a good health (1.30/CC).

b) Use of scientific knowledge

Differences in the decisions made were also seen when scientific knowledge was appealed to. Scientific ideas used by students were both correct and incorrect, as well as appropriately or inappropriately applied. In the mobile phones scenario (Figure 2, Box A), the majority of students that thought that mobile phones were harmful used incorrect or inappropriately applied ideas as justification:

> The microwave signal that we receive when we make a call can cause mutations in our cells (1.19/MP).

> There may be an effect on cells caused by waves, just like the Sun's waves cause skin cancer. Maybe cell phone waves can cause some kind of problem (2.3/MP).

In the scenario concerning genetically-modified humans (Figure 2, Box B), the two students that used scientific ideas were against this kind of treatment:

> I'm against it because modifying genes means causing mutations, and mutations are uncontrollable (1.56/MH).

In both scenarios, students used their scientific ideas to judge these applications of science and technology as harmful or dangerous, even though their ideas were incorrect or applied inappropriately. The opposite happened in the cloned cattle scenario (Figure 2, Box C), where the majority of students that approved consumption of foodstuffs from cloned animals made reference to scientific ideas.

> It's the same meat and milk, I mean, it's the same genetic material (1.34/CC).

Students that justified their decision by appealing to scientific knowledge mentioned that cloned animals would be identical to non-cloned animals. However, they paid no attention to the controversy—included in the scenario—surrounding this issue.

c) Use of other non-scientific factors

In the mobile phones scenario, (Figure 2, Box A), none of the students that appealed to non-scientific factors to make a decision thought that mobile phones were dangerous or harmful. Responses were divided between indecisiveness and the conviction that phones were safe. The main justification given was based on students' personal experience, since they stated that they had never met anyone with health problems due to mobile phone use.

Almost all students that were in favour of genetically-based therapies to correct mitochondrial defects (Figure 2, Box B) used these kinds of non-scientific justifications to reach a decision (mainly, risk/benefit analysis). This analysis, however, was not necessarily in-depth or took into account all the factors included in the scenario.

> It [the therapy] constitutes a means of improving people's life, I think it's OK to look for new experimental options (2.19/MH).

In the case of cloned cattle, (Figure 2, Box C), there is no clear-cut pattern in the decision-making of students that justified their decisions by appeal to non-scientific ideas: the number of students that answered Yes/No/I don't know was similar.

d) Summary of findings about the relationships between students' decisions and their justifications

In general, in all three cases the lack of evidence proved to be a relevant factor in students' decisions to accept or reject a given product or therapy, or at least show some uncertainty towards them. Scientific ideas played a variable role in students' decision-making, depending on the scenario. In the case of mobile phones, several students used their ideas about waves and cells to justify the perceived harmfulness of phones. On the contrary, in the cloned cattle scenario, students used knowledge of genetics to justify the perceived safety of foodstuffs from modified animals. The knowledge used was, for the most part, limited and, in some cases, it was applied inappropriately. In many cases, students did not consider all the scientific information provided as a basis for the assessment of the scenario. In the mitochondrial diseases scenario, students almost did not use scientific ideas at all. Lack of familiarity with, and remoteness from their everyday experience of, complex issues of genetics were the likely cause of the little use of scientific ideas.

When students used non-scientific decision factors, the degree of remoteness from the issue at hand seemed to also play an important role, given that, in the case of mobile phones, students tended to trust their personal experience—something that did not happen in other scenarios. When the degree of remoteness was considerable, such as in the case of mitochondrial diseases, students enacted a superficial risk/benefit analysis.

5.3.4. Changes in students' decisions in SSI scenarios after the course

In the following table, the number of students that changed their decision (and the direction of the change) after the course is shown.

Table 24 Numbers and frequencies of students that changed their decisions according to SSI scenario.

	MP	MH	CC
	n=29	n=35	n=29
I don't know→No	2	3	0
I don't know→Yes	2	1	2
No→ Yes	0	2	1
No→ I don't know	1	1	1
Yes→ No	0	0	3
Yes→ I don't know	2	1	3
Total changes	7	8	10
Frequency	0.24	0.23	0.34

MP: Mobile phones; MH: Modified humans; CC: Cloned cattle.

Several students changed their decision in all three scenarios. These changes did not follow a clear-cut trend and, together with their respective justifications, are explored below.

5.3.4.1. Changes in the mobile phone scenario

In this scenario, seven students changed their decision. There were no radical changes (i.e., from 'yes' to 'no' or vice versa); rather, students shifted from uncertainty to certainty or vice versa. There was no clear-cut trend in how the use of different justifications changed after the course. The justifications offered show that, in general (six out of seven instances), students assessed the scenario by appealing to one justification at the beginning of the course and a different one at the end. None of the students that used the lack of evidence as a criterion claimed that mobile phones are harmful. On the other hand, several of the students that did use this justification as a decision-making criterion claimed that mobile phones are not harmful.

Table 25 Students' decision changes and the justifications used in the mobile phone scenario

Number of students	Category of the initial justification	Category of the final justification	Example
I don't know → No			
1	More information is required	Caution due to the lack of evidence	*Initial*: I need more information about the way mobile phones work and what their effect is on the human body (1.7/MPf). *Final*: It hasn't been possible to prove that mobile phones are not harmful and I don't know anyone that has suffered any health problems caused by mobile phones (1.7/MPf).
1	Caution due to the lack of evidence	Confidence in personal experience	
I don't know → Yes			
1	Caution due to the lack of evidence	Justified scientific ideas	*Initial*: Because I would like to have a more concrete idea (1.17/MP). *Final*: Due to the fact that [mobile phones] emit radiation, and in the long term this radiation can cause ill-health (1.17/MPf).
1	More information is required	Unjustified scientific ideas	
Yes → I don't know			
1	Unjustified scientific ideas	Disagreement among scientists	*Initial*: Of the psychological, social kind (2.2/MP). *Final*; Because I've heard very different opinions and there is no consensus (2.2/MPf).
1	Justified scientific ideas	Caution due to the lack of evidence	
No → I don't know			
1	Caution due to the lack of evidence	Caution due to the lack of evidence	*Initial*: There hasn't yet been proof of their harmful health effects (1.45/MP). *Final*: There aren't enough grounds from which to make a decision (1.45/MPf).

In both cases where students changed from ‘I don’t know’ to ‘yes’, they also changed from a cautious attitude (which consisted of taking into account the lack of evidence or asking for more data) to a more definite position grounded on scientific ideas. This shift occurred in spite of the fact that the course did not cover the topics of radiation or cell phones. In this case, no student used risk/benefit analysis as a justification.

5.3.4.2. Changes in the modified humans scenario

Eight students (of 35) changed their decisions in this scenario. In what follows, the direction of the change is described in detail, together with the kinds of justifications given to support their decisions.

Table 26 Students' decision changes and the justifications used in the modified humans scenario

Number of students	Category of the initial justification	Category of the final justification	Example
I don't know → No			
2	Caution due to the lack of evidence	Caution due to the lack of evidence	*Initial*: There will always be a line in the sand between genetically modifying an embryo to cure a disease and doing the same to produce genetically-superior embryos (1.46/MH). *Final*: No, because this would allow creating big rifts in society—a division between those with resources and those without (1.46/MH).
1	Misuse of science	Misuse of science	
I don't know → Yes			
1	Caution due to the lack of evidence	Risk/Benefit analysis	*Initial*: I don't know, it would be good to avoid diseases and, what's more important, stop newborns' suffering (2.52/MH). *Final*: The majority of people that are born with a disease are discriminated against, insulted and attacked. This causes suffering to these people and to their families (2.52/MHf).
1	Risk/Benefit analysis	Risk/Benefit analysis	
Yes → I don't know			
1	Risk/Benefit analysis	Risk/Benefit analysis	*Initial*: If it represents an opportunity to improve the quality of life of people, I think that it's OK to look for new experimental alternatives (2.19/MHf). *Final*: When you modify genetically an individual, you're also modifying his or her personality, canceling or modifying the personality of an adult person. But, also, it might be that you're giving him or her a chance to improve their quality of life by improving their health—and their attitude to life might also change (2.19/MHf).
No → I don't know			
1	Risk/Benefit analysis	Caution due to the lack of evidence	*Initial*: These modifications would be significantly relevant for the life of the products, apart from being an important scientific advancement (2.32/MH). *Final*: Each one, as a person, knows what to do with his or her life, and I don't have that much confidence in this technique, because there must be a precautionary principle (2.32/MHf).
No → Yes			
1	Caution due to the lack of evidence	Risk/Benefit analysis	*Initial*: [I would need] solid grounds, or, rather, this theory hasn't been proven (2.7/MH). *Final*: Because it's a way of helping future generations and prevent genetic diseases that could be fatal (2.7/MHf).

In this case, the changes in decisions took place in various directions and there was no clear-cut trend towards a particular decision. From eight students, only one changed his or her view to the opposite one (from 'no' to 'yes'), whereas the other seven changed to, or from, uncertain positions. The student that changed his or her decision to the opposite one went from a justification based on caution due to lack of evidence to a risk/benefit analysis. In the majority of the cases, risk/benefit analysis led students to make a positive decision. This analysis was, however, superficial in all cases and failed to consider all factors mentioned explicitly in the scenario.

Unlike what happened in the mobile phone scenario, where students that changed their views used different justifications before and after the course, in this scenario five out of eight students used the same justification on both occasions, even though they changed their decision. This points to the relevance of aforesaid factors in students' decision-making, even though their analysis led them to different decisions or outcomes. This was the scenario that was the farthest from their everyday experience, which can influence how the controversy is assessed.

5.3.4.3. Changes in the cloned cattle scenario

In total, 10 students (out of 29) changed their decisions, before and after the course, in the cloned cattle scenario.

Table 27 Students' decision changes and the justifications used in the cloned cattle scenario

Number of students	Category of the initial justification	Category of the final justification	Example
I don't know → Yes			
1	* NA	Unjustified scientific ideas	*Initial*: I don't know, maybe not. It would be a question of quality on the part of the suppliers of of the foodstuffs (3.37/CC). *Final*: If it's like it has been stated, and the properties and quality have improved, I would certainly eat them (3.37/CCf).
1	More information is required	Endorsed/rejected by research	
Yes → I don't know			
1	Endorsed/rejected by research	Justified scientific ideas	*Initial*: If studies have been positive, I don't see why not eat it (1.57/CC). *Final*: Because, for the moment, there hasn't been enough progress in that field, due to social constraints. But I think that it would be safe, since the genetic code of a strong and healthy animal would be used and kept (1.57/CCf).
1	Justified scientific ideas	Risk/Benefit analysis	
1	Endorsed/rejected by research	More information is required	
No → I don't know			
1	Risk/Benefit analysis	Risk/Benefit analysis	*Initial*: I wouldn't feel completely safe—those foodstuffs might do me good or harm me (2.26/CC). *Final*: I don't know if they are safe or not, but no one can guarantee they are. Besides, if I have the possibility of having foodstuffs from a conventional animal, I don't see why not eat them (2.26/CCf).
No → Yes			
1	Caution due to the lack of evidence	Unjustified scientific ideas	*Initial*: I would wait for in-depth experiments to be done to determine if it's better or not (1.54/CC). *Final*: Because it's almost the other animal, but with better quality (1,54/CCf).
Yes → No			
1	Endorsed/rejected by research	Scientists have political/economic interests	*Initial*: Because if there's a way of improving the quality of the product and reduce the cholesterol or fat level, it would be convenient to approve it and nothing would be lost if it were to be eaten (1.49/CC). *Final*: Because time is needed to see if there are side effects—I would prefer to wait and see if they're not harmful for my body (1.49/CCf).
1	Risk/Benefit analysis	Caution due to the lack of evidence	
1	Confidence in personal experience	Caution due to the lack of evidence	

* NA was used when the students did not answer the open question in the questionnaire, answered 'I don't know', or his or her response was unclassifiable in one the available categories.

In this scenario there was also no definite trend in students' changes of decision or in the kinds of justifications given before and after the course. In this case there were radical changes of positions (four of them, from 'yes' to 'no' and vice versa). The majority of students (9 out of 10) changed the justification given for their decision at the beginning and at the end of the course. A characteristic of SSI is that they do not have a direct and easy answer, and various factors need to be considered in their assessment. This characteristic is reflected, in this case, in the high number of changes of justifications given by students.

In summary, the frequency of changes was similar in all three cases. These changes had distinct characteristics, according to the scenario. In the mobile phones and modified humans scenarios, changes from uncertainty towards certainty (and vice versa) prevailed (from 'I don't know' to 'yes' or 'no' or vice versa), whereas in the cloned cattle scenario there were more radical changes of decisions (from 'yes' to 'no' and vice versa). In spite of these differences in the way decisions changed, students that changed their opinion in the modified humans scenario used, in general, the same justification before and after the course. The opposite happened in the case of mobile phones and cloned cattle, where the justifications given before and after the course were more variable. In no case was it evident that the course had had an effect on the kinds of justifications given by students when they made a decision.

5.3.5. Students' responses to the remaining questions of the questionnaires

The purpose of the remaining questions of the SSI questionnaires was to probe students' views of the role of scientists and evidence, and about the role of consumers of therapies and/or products. Responses to these questions were not considered as justifications for the decisions made, since the questions were explicitly focused to determine students' ideas about specific topics that could have not played a role in their decision-making process. Consequently, only the analysis of responses given at the beginning of the course is presented, since there were no notable changes in students' responses after the course.

5.3.5.1. The role of scientists and evidence in the SSI scenarios

There were some differences in responses to the three episodes concerning the issues of the lack of conclusive evidence and the position of scientists in controversies.

In the mobile phones scenario, approximately half the students believed that evidence of the harm caused by mobile phones is trustworthy; the remaining half believed that it is not so. The majority of students that trusted the evidence argued that its trustworthiness stemmed from the fact that scientists and scientific institutions had conducted the experiments (14 out of 19):

> I believe it, because the institution charged with this research is serious. Besides, I don't think that it's a coincidence that several researchers have obtained similar results (1.23/MP).

Among those students that believed that the evidence is not trustworthy, ten (out of 17) commented that there are, as yet, no conclusive results upon which to make a decision:

> No, because more research would need to be done, since the results don't match each other (1.66/MP).

Five students answered that the evidence is not trustworthy because the modification of the cells has been proven, but the phenomenon has not been tested in other organisms, humans included—that is, extrapolation from one model to another is not yet possible:

> No, because, in spite of the studies with cells, it hasn't been possible to test it in higher organisms (1.40/MP).

Four students attributed the lack of conclusive evidence to the notion that the harm done by mobile phones is minimal and, consequently, difficult to detect. Three students attributed it to scientists' lack of knowledge:

> They might be the same tests, or it's simply a lack of knowledge with which to provide a better explanation and, from it, make the relevant tests (2.45/MP).

In the modified humans scenario, 18 students (out of 45) believed that disagreements among scientists concerning genetic therapy resulted from the technique not being entirely safe. One difference with respect to the previous scenario, however, is that a third of students considered ethical and moral aspects related to the issues scientists disagreed about (even when, in the scenario, these issues did not feature prominently):

> Because ethics is something that exists in all spheres and depends on the background and ideals of each person, so that each one having a different opinion is quite common. Another aspect to consider is that genetic modification of humans is not well accepted socially—mainly due to religion (1.15/MH).

Finally, when giving their opinions about the information published by scientists about the sale of foodstuffs from cloned cattle, 19 (out of 42) students agreed that this information is trustworthy and it is backed by experiments. On the contrary, 12 students believed that scientists lie or are influenced by monetary interests, making the consumption of these foodstuffs unsafe. Generally speaking, in both views students used superficial arguments to justify their positions, and ignored the information presented in the texts themselves:

> I think that what they say is true—I agree with them. Today, science has no limits. And, besides, that is a new way of reproducing animals without the need of sexual reproduction (1.31/CCf).
>
> That it is trustworthy, because at least I haven’t heard of someone dying after eating those products (1.57/CCf).
>
> I think that it can’t be true that cloned foodstuffs are the same as conventional ones. And, if it’s false, it wouldn’t them any good to publish it (2.26/CC).

In summary, a common element in all SSI scenarios is that a little less than half the students believed that the available evidence up until now and scientists’ opinions are trustworthy and objective. A common argument in all scenarios was the lack of evidence about the absolute safety of the products or therapies. However, the rest of the students believed that the controversy was due to scientists not being objective enough, since they must be influenced by their ideas about ethics or religion (in the case of modified humans) or by their political and monetary interests (mainly in the case of cloned cattle).

5.3.5.2. The role of consumers in SSI scenarios

The precautionary principle was—given the number of references by students—a common element in the scenarios.

When students were asked for their thoughts on the fact that recommendations had been issued—without conclusive evidence at hand—concerning the use of mobile phones, 31 (out of 37) students commented that they thought it appropriate and made reference to the precautionary principle. Five students thought that it is incorrect for these kinds of unwarranted recommendations to be published because they cause undue panic and alarm:

> They only scare people; they are only speculations and cause doubts. But, as long as we don't know, the safest thing to do is not to believe (1.40/MP).

In spite of the fact that 31 students claimed that the issuing of these recommendations was an adequate decision, thirteen claimed that they would not follow them, either because they remained unconvinced by the evidence, because their habits are difficult to change or because they have not heard of cases of harm being caused:

> I would try something for some time, but due to my habits and the social milieu, I don't think I would keep doing it for a long time (2.15/MP).

In the cloned cattle scenario, 16 students (out of 40) thought that it is all right for consumers to apply the precautionary principle as long as there is no certainty about these kinds of products. Eight students believed that consumers disagreed with the consumption of these products because they lack information. Two students commented that people are afraid to try them. Six students answered that these products are an alternative that consumers are free to choose.

In the case of mitochondrial diseases, the majority of students (36 out of 44) argued that parents are the ones that should make the decision whether to modify the embryos genetically. The justifications given for such a decision were that parents are the ones that will have to deal directly with the consequences (26); know, and want, what is best for their children (5); and need orientation to decide what to do (5). Some students (2) mentioned that the decision to modify embryos genetically should be placed in the hands of health organisations; on committees integrated by parents, scientists and members of government (2); and on scientists, who must, since they are the ones that understand the issue, make the decision (2). Finally, two students commented that nobody has the right to decide on the life of others.

In general, the precautionary principle was a relevant factor with which to face the situations presented by the SSI. However, for several students factors such as convenience influenced their perception of the SSI.

In the mobile phone scenario, several students disagreed with the information about potential risks being spread—it is likely to cause fear among people. However, in the cloned cattle scenario, several students believed that consumers fear these products because they lack information. Information also played a relevant role in the modified humans scenario, particularly when students were asked about who is responsible for deciding whether or not these procedures are allowed: several students attributed the responsibility to parents, but only if they have enough information. Unlike the other two scenarios, in the modified humans scenario more ethical and moral aspects entered into the picture.

5.4. Scenarios about well-established science

In the well-established science scenarios, students had to make a decision about non-controversial issues such as smoking, self-medication, and the benefits of a healthy lifestyle. In the self-medication scenario, students faced a hypothetical case of a young person that indulges in the practice of self-medication. On the contrary, in the smoking and healthy lifestyle scenarios, students made a decision that concerned their own habits.

5.4.1. Students' decisions about well-established science scenarios

In the first question of the well-established science scenarios, students had to make a decision. The questions can be seen in Table 28. The full scenarios are available in Appendix B.

Table 28 Decision-making questions for the different scenarios.

Code	Scenario	Question
SM	Self-medication	Do you think José should have taken the antibiotic?
SK	Smoking	Do you smoke?
DD	Diet and diabetes	Do you lead a healthy life-style?

In the following table, students' decisions are summarised for all three scenarios. With the aim of determining the changes in the proportions of students between initial and final responses, only those from students that completed the questionnaire both at the beginning and at the end of the course were considered in the analysis.

Table 29 Decisions of students for each well-established science scenario, before and after the course.

	Before			After		
	SM (n=29)	**SK** (n=35)	**DD** (n=29)	**SM** (n=29)	**SK** (n=35)	**DD** (n=29)
Yes	1	7	17	0	7	17
No	26	28	12	22	28	11
I don't know*	2	--	--	6	--	--
Non-response	0	0	0	1	0	1

* For the smoking and healthy lifestyle scenarios, only the options 'Yes/No' were offered.

The majority of students were against self-medication both before and after the course. The majority of students also claimed to be non-smokers. Both at the beginning and at the end of the course, the majority of students claimed to lead healthy lifestyles.

5.4.2. Students' justifications of their responses to the well-established science scenarios

The second question of the questionnaire asked students to justify their decision. The following table summarises students' justifications. In this case, justifications from all questionnaires were taken into account, so as to have the largest possible collection of responses. Descriptions of the categories are detailed in Table 13. Unused categories were omitted from Table 30 for purposes of clarity.

Table 30 Number of instances of each category and subcategory for each scenario, before and after the course.

Category	Subcategory	Before SM n=38	Before SK n=44	Before DD n=43	After SM n=28	After SK n=41	After DD n=30
Related to the NOS	Appeal to authority	6 (.16)	1 (.02)	0 (0.0)	**6** (.21)	0 (0.0)	0 (0.0)
Scientific knowledge	Justified scientific ideas	4 (.11)	0 (0.0)	0 (0.0)	4 (.14)	0 (0.0)	0 (0.0)
	Unjustified scientific ideas	5 (.13)	**9** (.20)	3 (.07)	1 (.04)	**10** (.24)	6 (.20)
More information is required		**12** (.32)	0 (0.0)	0 (0.0)	6 (.21)	0 (0.0)	0 (0.0)
Trust in other sources	Confidence in personal experience	0 (0.0)	1 (.02)	0 (0.0)	1 (.04)	1 (.02)	0 (0.0)
Personal interests/preferences		0 (0.0)	**24** (.55)	**22** (.51)	0 (0.0)	**29** (.71)	**14** (.47)
Risk/benefit analysis		**10** (.26)	6 (.14)	0 (0.0)	**9** (.32)	1 (.02)	1 (.03)
Alternatives	Helplessness/resignation	1 (.03)	3 (.07)	0 (0.0)	1 (.04)	0 (0.0)	0 (0.0)
Others		0 (0.0)	0 (0.0)	**18** (.42)	0 (0.0)	0 (0.0)	**9** (.3)

Frequencies of responses are shown between brackets.
The highest frequencies are shown in bold.

The range of justifications used when addressing the well-established science scenarios was less broad than that used in the pseudoscientific and the SSI scenarios. Few students used ideas about the NOS as the basis for their decisions in this kind of scenario. The subcategory of the NOS that was used was the appeal to authority, especially in the self-medication scenario.

> Because one always must go to the doctor before taking any drug (1.41/SM).

Many students used unjustified scientific ideas, especially in scenarios about smoking and about diet and diabetes. These ideas generally took the form of ready-made phrases or clichés that do not guarantee any understanding on the part of the student.

> Because they [cigarettes] are addictive (1.32/SK).

> Because these kinds of vices [smoking] are very hard to control, and they also cause various diseases (2.31/SK).

Many students claimed that it is harmful to self-medicate because there is not enough information about diseases and their treatments, even though the majority confessed to having self-medicated at least once.

> Because he was unaware of the nature of his disease, and he didn't know if the antibiotics were the right treatment for him (1.17/SM).

In the scenarios about smoking and about diet and diabetes, the preferences and personal interest carried a lot of the weight of the decision.

> Sometimes it [smoking] helps me to relax (1.44/SK).
>
> I do not exercise because I get tired (1.47/DD).

Even though the three scenarios dealt with health issues students can act upon, the risk/benefit analysis was only mentioned in the smoking and self-medication scenarios.

> He wasn't even sure why he felt sick and taking antibiotics without a prescription is worse than not taking them (1.7/SM).
>
> I like sports, and if I smoke, it would affect my body; this would stop me from doing what I like (1.2/SK).

Finally, other practical considerations, such as lack of free time or money, bore heavily on decisions to lead a healthy lifestyle.

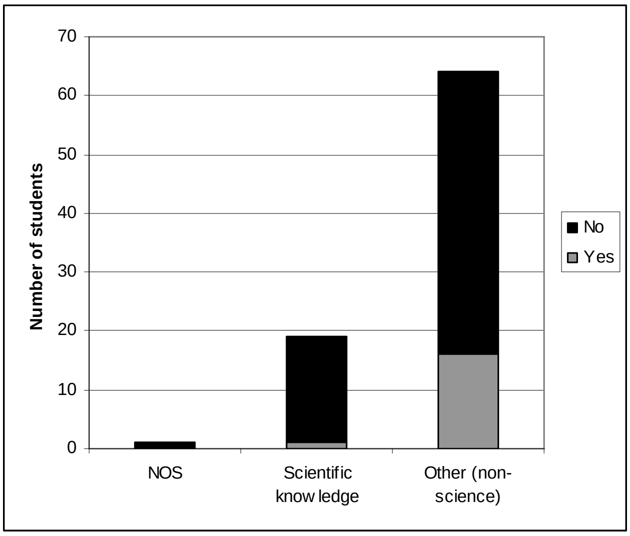
> Sometimes [I don't exercise] because of the money or because I don't have the time to exercise (1.16/DD).

5.4.3. Students' decisions and their relationship to justifications

So far, results suggest that the three scenarios elicit different responses in students. In the self-medication one, students for the most part claimed that José needed more information or, alternatively, based their decisions on a risk/benefit-analysis. On the other hand, in the smoking and diet and diabetes scenarios, personal interests had more weight in decision-making.

In the self-medication scenario, regardless of their respective justification, almost all students responded negatively, that is, were against this practice. In contrast, in the smoking and diet and diabetes scenarios students responded both positively and negatively. Is there any relationship between the justifications given in these last two scenarios and students' positive or negative response? To find out, students' responses were plotted (Table 30) against the type of justification given in each case. The total number of responses, both before and after the course, was plotted.

A



B

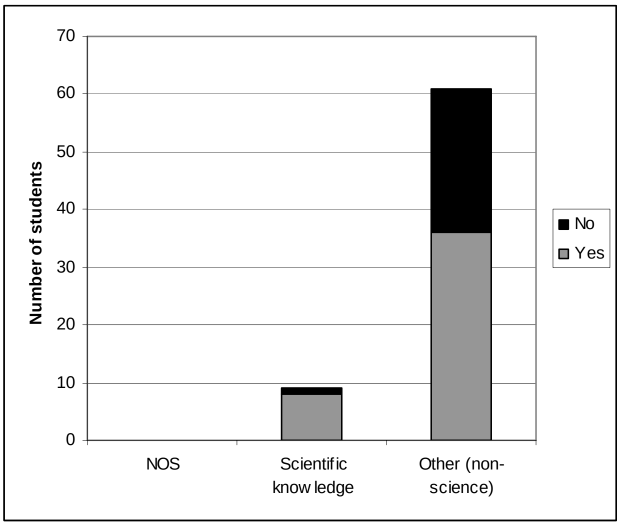


Figure 3 Number of students that answered Yes/No/I don't know, grouped according to the type of justification given. Box A: Smoking scenario; Box B: Diet and diabetes scenario.

In neither of the two scenarios did ideas about the NOS play a role. On the contrary, unjustified scientific ideas did play a role in both cases. In the smoking scenario, almost all students that used scientific ideas claimed not to be smokers. Both smokers and non-smokers mentioned more frequently practical and personal factors as justifications for their decisions.

In the diet and diabetes scenario, almost all students that used unjustified scientific ideas claimed to lead healthy lifestyles. In this case, factors unrelated to science played a more prominent role in justification, both for students that lead healthy lifestyles and those that do not.

It seems that scientific ideas—mainly unjustified—are associated with healthy practices, whereas other factors, of a more practical nature, are associated with both decisions.

5.4.4. Changes in students' decisions in the well-established science scenarios after the course

In the following table, changes in decisions in the well-established science scenarios, and the direction in which they occurred, are summarised.

Table 31 Numbers and frequencies of students that changed their decisions according to well-established science scenario

	SM	SK	DD
	n=29	n=35	n=29
I don't know→No	0	0	0
I don't know→Yes	0	0	0
No→ Yes	0	1	1
No→ I don't know	4	0	0
Yes→ No	1	1	1
Yes→ I don't know	0	0	0
Total changes	5	2	2
Frequency	0.17	0.06	0.07

SM: Self-medication; SK: Smoking; DD: Diet and diabetes.

In the well-established science scenarios, changes of decisions were less frequent, compared to the pseudoscience and SSI scenarios. The scenario with the highest number of changes was the self-medication one, where four students changed their decision from 'No' to 'I don't know', and one from 'Yes' to 'No'. In the following tables, changes of decision in each scenario are detailed.

5.4.4.1. Changes in decision in the self-medication scenario

Table 32 Students' changes of decision and the justifications used in the self-medication scenario

Number of students	Category of the initial justification	Category of the final justification	Example
Yes → No			
1	Unjustified scientific ideas	Risk/benefit analysis	*Initial*: Because those weren't serious symptoms. Besides, drugs packages say what diseases they are recommended for (1.6/SM). *Final*: Because the disease could have gotten more complicated or he could have poisoned himself without him knowing (1.6/SMf).
No → I don't know			
1	Appeal to authority	Resignation	*Initial*; Because the adequate dosage is not known, and he didn't went to a doctor to get a prescription of what he needs (1.20/SM). *Final*: Because, in part, I think that it is wrong to self-medicate, but that's what the majority of us do (1.20/SMf).
1	Appeal to authority	More information is required	
1	More information is required	Risk/benefit analysis	
1	More information is required	Confidence in personal experience	

In this scenario, all students that changed their decision also changed their justification. There was no identifiable pattern in the trends of change of decisions and justifications, since these last were not the same at the beginning and at the end of the course.

5.4.4.2. Changes in decision in the smoking scenario

Only two students changed their decisions in this scenario. This low frequency of change is to be expected since smoking is a hard to abandon habit. In this case, a student commented that at the beginning of the course he did not smoke, but at the end he did, whereas another student went from being a smoker to a non-smoker.

Table 33 Students' changes of decision and justifications used in the smoking scenario

Number of students	Category of the initial justification	Category of the final justification	Example
Yes → No			
1	Personal interest	Personal interest	*Initial*: Because I like it, although I've seen the negative effects (2.35/SK). *Final*: It don't find it pleasurable (2.35/SKf).
No → Yes			
1	Unjustified scientific ideas	Personal interest	*Initial*: Because I'm aware of the damage that cigarettes cause and because I don't want to grow dependent on such a thing (1.29/SK). *Final*: Out of curiosity, first and foremost of knowing what cigarettes taste like (1.29/SKf).

The student that started smoking went from considering cigarettes to be harmful and addictive to justifying his decision on personal taste or interest. On the contrary, the student that smoked at the beginning of the course but had stopped at the end relied, in both cases, on the taste or distaste for cigarettes as a justification.

5.4.4.3. Changes in decisions in the diet and diabetes scenario

Only two students changed their opinion in this scenario. Just like in the smoking scenario, diet and exercise habits seemed to remain stable. A student claimed that at the beginning of the course he led a healthy lifestyle but at the end he didn't. Another student commented that at the beginning he did not lead a healthy lifestyle, but at the end he did. It is worth mentioning that, unlike the decision to smoke or stop smoking, lifestyle decisions depend on subjective perceptions that can change. It is quite possible that changes in responses to this scenario are due to changes in students' perception of their own lifestyle and not to an actual change of habits.

Table 34 Students' changes of decision and justifications used in the diet and diabetes scenario

Number of students	Category of the initial justification	Category of the final justification	Example
Yes → No			
1	Others	Personal interest	*Initial*: I take care to have a balanced diet, because I strive to be thin (1.25/DD). *Final*: I would make the decision of having a balanced to take care of my health (1.25/DDf).
No → Yes			
1	Others	Personal interest	*Initial*: Well, sometimos because of money or lack of time to do it properly (1.16/DD). *Final*: That's part of each person's education, of their lifestyle (1.16/DDf).

Both students changed their justifications from 'other factors' (in this case, being thin or having time and money) to interest or personal taste.

5.4.5. Students' responses to the remaining questions of the questionnaires

The three scenarios about well-established science asked students to make a decision about a health issue about which there is enough evidence. The remaining questions of the questionnaires aimed to determine more about students' beliefs of the role of evidence and its trustworthiness, as well as of the effect such evidence has on everyday decisions.

5.4.5.1. The role of evidence in the well-established science scenarios

In the three scenarios, almost all students agreed that there exists enough evidence to demonstrate the damage caused by self-medication (34 out of 38) or a sedentary lifestyle (39 out of 42).

When students were asked what constitutes evidence in each scenario, 26 students (out of 38) claimed that evidence of the damage caused by self-medication consists of the number of deaths or negative outcomes in people that self-medicate. In the smoking scenario, the number of cases of disease and death was also the kind of evidence most mentioned (43 out of 46), as was the case of the relationship between diabetes and diet (23 out of 42). Only five students made reference, as examples of evidence, to microbial resistance to antibiotics in the case of self-medication, and two mentioned that the toxic substances in tobacco have been characterised. In the diet and diabetes scenario, eleven students claimed that the evidence is palpable in everyday life—overweight or sedentary people tend to get diabetes.

Generally speaking, almost all students agreed that the evidence is trustworthy, even though the reasons for trusting it varied. In the self-medication scenario, eleven students (out of 38) argued that the evidence was trustworthy because it is evident (for example, the number of deaths), nine claimed that enough tests have been done, and six believed that the evidence is trustworthy because it was gathered by experts.

In the smoking scenario, 20 students (out of 46) claimed that the evidence is trustworthy because people do get sick and there are records and statistics of deaths and diseases. Five students believed that the evidence is trustworthy because it was obtained by experts, whereas nine thought that it is trustworthy because they themselves had seen cases of respiratory illnesses caused by smoking.

Finally, in the diet and diabetes scenario, 38 students (out of 42) thought that the evidence is trustworthy mainly because diabetes is a disease that has been widely studied and many people suffer from it. Also, some claimed that people they personally know have diabetes. Five students commented that the evidence is trustworthy because it was gathered by experts.

Basically, students gave three different reasons for trusting the evidence: the availability of statistics and published information, experts' advice, and the fact that the evidence coincides with their personal experience and expectations.

5.4.5.2. The impact of information and evidence in students' decision-making

Once students had accepted that there is enough evidence and that it is trustworthy, they were asked whether they would self-medicate again, change their lifestyle for a healthier one, or what was their opinion on the anti-tobacco law.

After being made aware of the risks involved in self-medication, seven students kept claiming that they would self-medicate if needed, mainly out of habit or limited access to doctors. In the diet and diabetes scenario, when students were asked about what would make them change their lifestyles for a healthier one, 17 (out of 42) claimed that they would change if they were ill, seven argued that they would need more time or money to enact a change, six said they would need more motivation, and four asked for more, in-depth information about the risks of leading an unhealthy lifestyle before deciding to change.

Almost all students (42 out of 47) supported the anti-tobacco law, arguing that non-smokers' health deserves to be kept safe from the noxious effects of tobacco smoke. Out of the five students that did not agree with the law, two believed that it would have been better to completely prohibit tobacco, whereas three believed that doing so would constitute a discriminatory measure. A total of 38 students disagreed with the prohibition of tobacco, the majority arguing that each person is free to decide as he or she sees fit and are, thus, responsible for their own choices. Even so, several students emphasised the need to provide information to people and to enact regulation akin to the anti-tobacco law.

5.4.5.3. Summary of the three scenarios

In general, all students tended to trust the evidence and scientists in the well-established science scenarios. The main source of evidence cited in all three cases was the number of ill people or deaths caused by self-medication, smoking, and a sedentary lifestyle. The reasons cited for trusting the evidence were mainly three: statistical data have been widely publicised; the evidence was obtained by experts; the student had a personal experience that confirms the evidence.

In spite of the fact that students knew of the risks of self-medication, smoking, and a sedentary lifestyle, several students seemed unwilling to enact a lifestyle change, mainly due to habit or apathy. Some students claimed that they would only change their lifestyles if they were diagnosed with a disease.

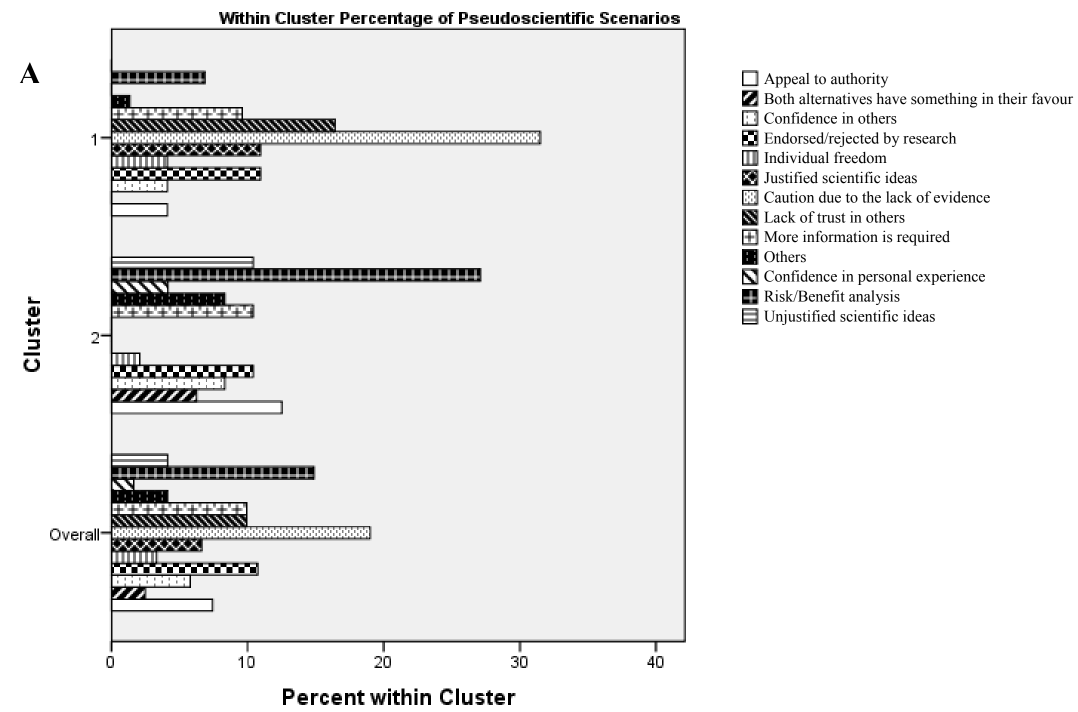
5.5. Students' patterns of response

Up until now, decisions and their justifications have been analysed individually for each of the nine scenarios, grouped according to the kind of scenario they belong to (pseudoscientific, SSI, or well-established science), and differences among them have been found. However, each student completed three scenarios, one of each kind. Are there any patterns in students' justifications for all three scenarios they completed? Did students repeat the use of a particular kind of justification in more than one scenario? In order to determine the existence of patterns in students' justifications, a cluster analysis was performed.

There was no cluster formation after performing the cluster analysis of justifications for all three scenarios, both before and after the course. A second analysis was performed with responses given only at the beginning of the course for all three different kinds of scenarios. Still, there was no adequate cluster formation. A detailed inspection of the results of this last analysis revealed that well-established science scenarios were preventing adequate cluster formation. This was not unexpected, since responses to this kind of scenario were very different from the ones to the other scenarios—i.e., pseudoscientific and SSI. For this reason, only the relationship (or lack thereof) between students' responses to the pseudoscientific and SSI scenarios was subsequently explored.

5.5.1. Cluster analysis of the pseudoscientific and SSI scenarios at the beginning of the course

As a result of the cluster analysis performed with students' justifications at the beginning of the course, both in the pseudoscientific and SSI scenarios, students were separated in two clusters. Figure 4 shows the percentage of each justification in each of the two clusters for both the pseudoscientific (Box A) and SSI (Box B) scenarios.



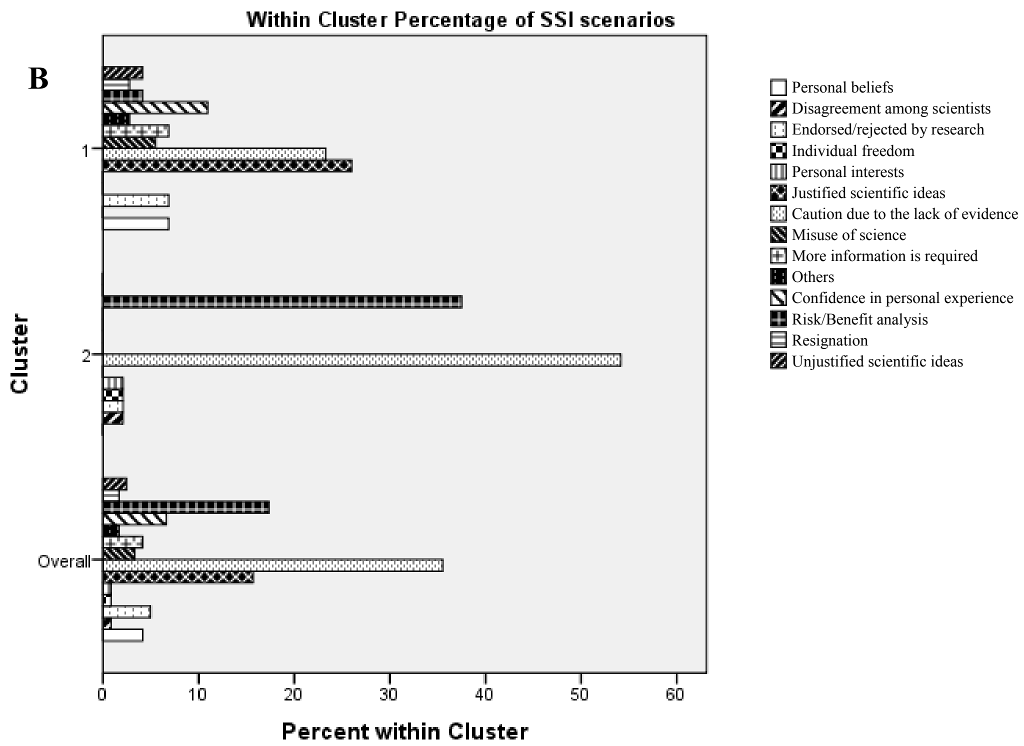


Figure 4 Percentages for each justification in pseudoscientific (Box A) and SSI (Box B) scenarios.

In the case of pseudoscientific scenarios (Figure 4, Box A), cluster 1 grouped mainly students that used, as justifications, the caution due to the lack of evidence, the lack of trust in non-scientific agents, justified scientific knowledge, and the endorsement/rejection by scientific research. Cluster 2 grouped the majority of students that used risk/benefit analysis, appealed to authority, used unjustified scientific ideas, asked for more information, or used as a criterion the endorsement/rejection by scientific research.

In SSI scenarios (Figure 4, Box B), cluster 1 grouped mainly students that used justified scientific ideas and caution due to the lack of evidence, whereas cluster 2 also grouped students that used caution due to lack of evidence and risk/benefit analysis.

In broad terms, students in cluster 1, for both scenarios, tended to use more their knowledge about specific topics and about how science works in order to make a decision (by appealing to the precautionary principle, the lack of trust in non-scientific agents, their scientific knowledge, and the endorsement/rejection by research). On the other hand, students in cluster 2 relied more on forms of analysis or argument commonly used when there is a lack of evidence, such as risk/benefit analysis, appeal to authority, the demand for more information, and caution due to lack of evidence.

5.5.2. Cluster analysis of pseudoscientific and SSI scenarios at the end of the course

Unfortunately, no clear clusters were formed when justifications to the pseudoscientific and SSI scenarios before and after the course were used as input in the analysis. For this reason, the analysis of justifications before and after the course was conducted separately.

It is likely that the absence of clear clusters after performing the analysis results from differences in the patterns of students' responses shown previously (Table 23 and Table 30).

In the following figures, the cluster composition at the end of the course for the pseudoscientific (Figure 5, Box A) and SSI (Figure 5, Box B) scenarios are shown.

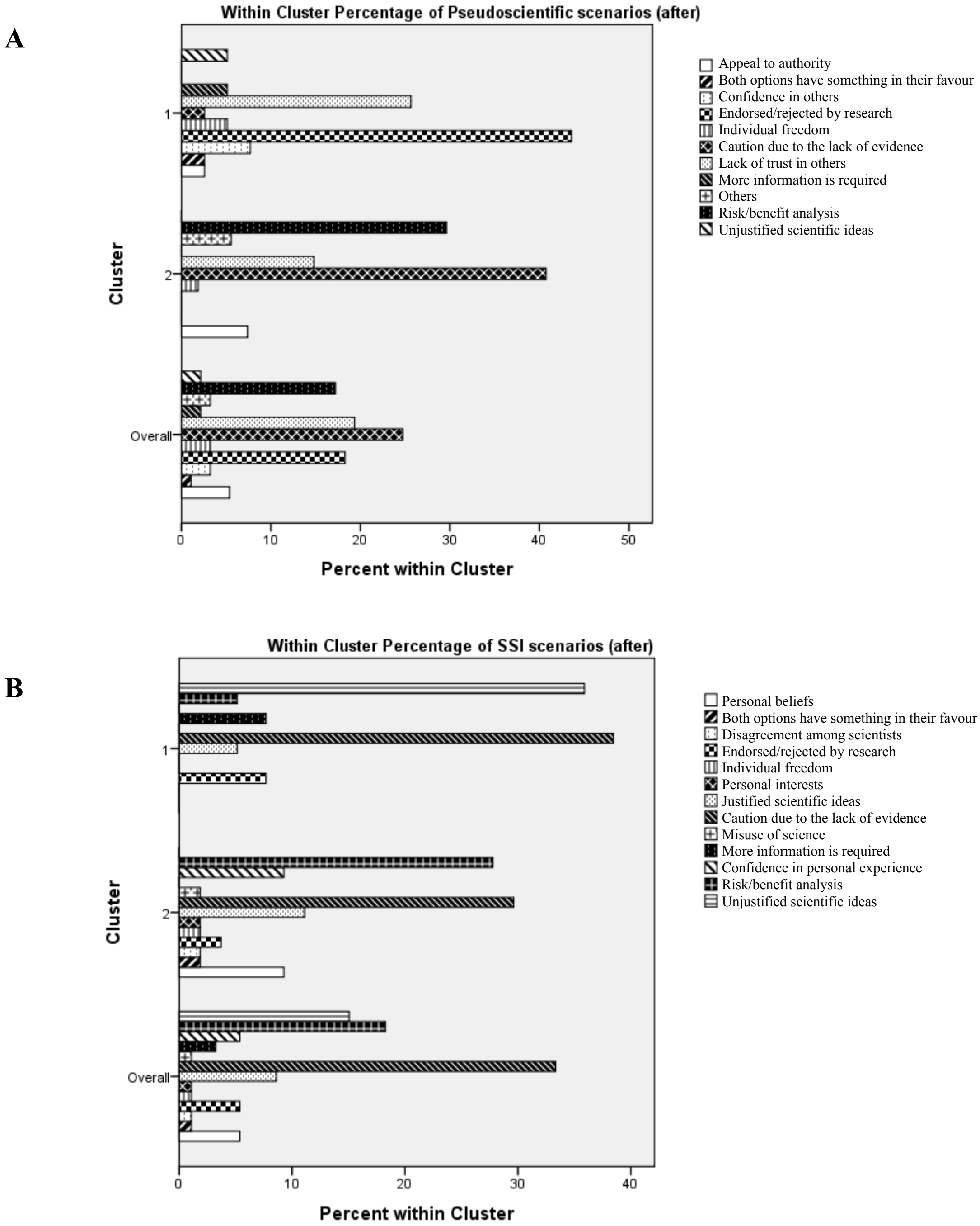


Figure 5 Percentages for each kind of justification in the clusters formed for pseudoscientific (Box A) and SSI (Box B) scenarios.

In pseudoscientific scenarios, cluster 1 included mainly students that used as criteria the endorsement/rejection by research and the lack of trust in non-scientific agents, whereas cluster 2 included mainly students that used the lack of evidence and risk/benefit analysis as criteria.

On the other hand, in SSI scenarios, cluster 1 is made up mainly of students that used unjustified scientific ideas and caution due to lack of evidence, whereas cluster 2 grouped mainly students that relied on a risk/benefit analysis or that showed caution due to the lack of evidence.

In this case, cluster 1 formation in both scenarios appears to be characterised by trust in science, whereas cluster 2 formation is characterised by criteria related to lack of information, such as caution due to lack of evidence and risk/benefit analysis.

5.5.3. Summary of students' patterns of responses before and after the course

Both before and after the course, students were separated in two clusters. Due to the variety in the responses given by students, the clusters did not form clearly and unambiguously. However, when both clusters were compared, both before and after the course, two different trends that guided decisions were identified: on the one hand, those related with scientific knowledge, knowledge of how science works, and trust in science (and distrust in non-scientific agents) were grouped in cluster 1. In the other, justifications unrelated to science, such as risk/benefit analysis and the demand for more information were grouped mainly in cluster 2.

It was found that caution due to lack of evidence was associated with different clusters. This justification does not necessarily reflect students' scientific knowledge, but is indicative of students that understand the role of evidence and its relevance in making a decision.

5.6. Summary of results

In the pseudoscience scenarios, prior familiarity and amount of knowledge about the issue were crucial in determining which factors are used by students to justify their decisions. When there was familiarity with the scenarios—as in the case of Aids and diet—students used more ideas of the NOS (the role of evidence, support if scientific research, and the trustworthiness of scientists). These students tended to reject pseudoscientific arguments and trust scientists. In contrast, when the situation was unfamiliar—as in the quantum medicine scenario—students used, besides caution due to the lack of evidence, non-scientific criteria to make a decision, such as risk/benefit analysis. This kind of analysis led several students to accept pseudoscientific claims, distrust scientists and their arguments, and judge as plausible the mechanisms of action proposed by the defenders of these therapies.

In SSI scenarios, students' responses and justifications appeared also to be influenced by the context. A common idea used in all scenarios was the caution due to the lack of evidence, but when students used other factors to decide, these were context-dependent. In the topic closest to their experience—mobile phones—students showed more uncertainty in their decision. In this case, personal experience and justified scientific ideas (mainly superficial or mistaken) played a role in decision-making. In the scenario about cloned cattle, the degree of uncertainty was intermediate within the three scenarios. Endorsement/rejection by research and justified scientific ideas were the most common justifications. In the topic farthest away from their experience—modified humans—students' responses were in general clear-cut and exhibited certainty. In this scenario, the analysis of risk/benefit was the main criterion. Approximately half of the students believed the evidence in the scenarios was not trustworthy due to the lack of objectivity of scientists and their personal interests or due to methodological difficulties.

In the scenarios of well-established science, students' views of the NOS did not play a crucial role. Only a few students used the criterion of appeal to scientific authority in the self-medication scenario. In the scenarios about diet and diabetes, students that used scientific ideas to justify their habits tended not to be smokers themselves and led healthy lifestyles. The majority of students used ideas unrelated to science to justify their decisions. Within these were practical considerations and tastes/personal interests, mainly. Almost all students trusted the scientific evidence presented in the scenarios, either because there are publicly-available statistics, because it was obtained by experts or because they have personal experience that supports the evidence. Several students mentioned that they would not change their unhealthy lifestyle because they could not be bothered to change their habits or because they lacked the motivation to do so.

The course did not seem to have an effect on the decisions and justifications given for any of the scenarios. The results of the cluster analysis show that there were two groups of students, classified according to the type of justification used. The first group tended to use justifications related to scientific knowledge and the NOS (together with lack of trust in non-scientific agents). The other group used considerations like the risk/benefit analysis and the demand for more information. In both groups students used also the criterion of caution due to the lack of evidence.

So far, the results of the decision-making questionnaires have been described. In the next chapter these results, together with the results from the SUSSI questionnaire, will be discussed and related to the relevant literature.

Chapter 6. Discussion

In the previous two chapters the results of the SUSSI questionnaire, concerning students' views of the NOS, and of the decision-making questionnaire were presented—both for before and after the course. In the present chapter, these results will be discussed and interpreted in the light of the relevant literature. The chapter is organised around two main sections. In the first one, the results of the questionnaire about students' views of the NOS will be discussed and compared with those of Liang et al.'s (2009) original study. Furthermore, the implications of having adequate views of the NOS for decision-making will be addressed. In the second section, the results of the decision-making questionnaire will be discussed, and the influence of the context on the use of different kinds of justifications in support of students' decisions will be analysed.

6.1. Students' views about the NOS: SUSSI Questionnaire

Presently, many science education programmes include, to a greater or lesser degree, the NOS as a topic. It has been argued (Thomas and Durant, 1987; Lederman, 2007) that understanding the NOS helps students, among other things, to make sense of science, make informed decisions about SSI, appreciate the relevance of science in society and its inherent cultural worth.

In spite of efforts to incorporate aspects of the NOS in science curricula, numerous studies (for example, see Driver et al., 1996; Lederman, 2007) suggest that students' views of the NOS are inadequate and difficult to change.

In Mexico, topics related to the NOS were part of the most recent reform, in 2006, of the science curriculum of secondary schools and of some science—and/or technology—oriented university degrees (Secretaría de Educación Pública, 2006). Those students that participated in the present study were first semester chemistry undergraduates. As part of their coursework, they were enrolled in a course about the relationships between science and society. One of the aims of this course is to foster an understanding of the historical, philosophical, social, ethical, and political aspects of science through the study of chemistry-related issues.

Teachers rely on readings, debates, analysis of videos, group discussions, and essay writing to achieve the aims of this course, among which is promoting an understanding of the NOS. In the first teaching unit, students studied historical aspects of science and technology, the profile of the modern scientist, and the features of scientific work.

In order to determine the effect of the course on students' views of the NOS, the present study assessed their views at the beginning and at the end of the course. Accordingly, the Student Understanding of Science and Scientific Inquiry (SUSSI) questionnaire was administered. In the following sections the questionnaire results will be discussed.

6.1.1. The questionnaire and its reliability

The SUSSI questionnaire, developed and validated by Liang et al. (2008), comprises six topics, each one of which offers to respondents a four-item Likert scale followed by an open question. The topics addressed by the questionnaire are observations and inferences, the tentativeness of scientific knowledge, scientific theories and laws, social and cultural embeddedness, creativity and imagination, and scientific methods. Said questionnaires were administered by the authors of the SUSSI to a sample of pre-service teachers in China, Turkey, and the United States.

For the purposes of the present study, the reliability of the instrument was determined through calculating Cronbach's alpha. The calculated value of alpha for the full questionnaire was 0.75, considerably higher than the value of 0.69 obtained by the original authors (Liang et al., 2008).

Values of Cronbach's alpha for each of the topics of the NOS covered by the questionnaire were also different from those calculated in the original study. These values are shown in Table 35.

Table 35 Comparison of the values of Cronbach's alpha obtained by the original authors and those calculated in the present study.

NOS Topic	Cronbach α Liang (2008)	Cronbach α
Observations and inferences	0.61	0.53
Tentativeness	0.56	0.51
Scientific theories and laws	0.48	0.31
Social and cultural embeddedness	0.64	0.65
Creativity and imagination	0.89	0.84
Scientific methods	0.44	0.65

Cronbach's alpha for observations and inferences, tentativeness, scientific theories and laws, and scientific methods were smaller than Liang et al.'s (2008). This could mean that there was a higher variability in responses to the items of each of the topics. The most striking difference was found in the topic of scientific theories and laws. The low alpha value seen in this topic might be due to the fact that some students used an informed view to answer the items of this topic, whereas other students used a naïve view. This issue will be discussed in a future section. On the contrary, for the topics of social and cultural embeddedness and scientific methods, alpha values were higher in the present study. Besides Cronbach's alpha, the coherence between responses to the open questions and Likert scale items indicates the reliability of the instrument and helps assess in more depth students' views.

6.1.2. Students' views on observations and inferences

Many students believe that scientists are more objective than other professionals. As a consequence of this, two scientists that observe the same event should interpret it identically (McComas et al., 1998). This misconception has the unintended and negative effect that disagreements among scientists could be interpreted by students as the result of inefficiency, ignorance, or as a result of their personal interests. This misinterpretation could, in its turn, inhibit a deeper analysis of the actual causes of the disagreement.

The scores calculated by Liang et al. (2009) for this topic and for the samples of Turkey, China, and the United Status (14.49, 14.69, and 15.98, respectively) were similar to those obtained in the present study (14.31 for Group 1 and 14.72 for Group 2 at the beginning of the course, Table 10).

Like in the original study, the majority of the students agreed that scientists' interpretations of the same observation can vary (Statement 1D). However, in spite of this response a high proportion of students in both studies believed that observations need to be the same because scientists are objective (Statement 1B). In the present work, open responses helped to clarify that this discrepancy is due to students' way of interpreting Statement 1D: some students attributed the different interpretations to the inefficacy of scientists, different ways of making the experiments, or mistakes. This suggests that students might have a naïve view, even though they selected the 'desired' point in the Likert scale.

Aikenhead and Ryan (1992) have described in the past the series of problems associated with students' interpretations of closed-ended items. They found that there can be several reasons why a student might agree or disagree with a given statement. In the case of the present study, students agreed on the fact that scientists' interpretations of the same data can differ, not because they are influenced by theory but because errors or failures in scientific processes happen.

This view of scientists' objectivity is quite common, and it has been suggested that it is one the hardest misconceptions to change in students (for example, see Akerson et al., 2000; Abell et al., 2001; Khishfe and Abd-El-Khalick, 2002).

In spite of the fact that in the SUSSI questionnaire the problem of different students' interpretations is present in many topics, its reliability is enhanced by the presence of the open-ended question that allows a more in-depth probing of students' views, thus increasing the usefulness of the SUSSI questionnaire as a diagnostic instrument.

6.1.3. Students' views about the tentativeness of science

There is a widespread view that says that once enough evidence has been carefully collected, scientific knowledge will not change anymore (McComas et al., 1998; Khishfe and Abd-El-Khalick, 2002). If students do not grasp that scientific theories and laws are susceptible to revision, changes to them can be a source of distrust. In order to gain a more comprehensive view of the NOS, students should understand that different scientific ideas have different degrees of tentativeness; that ideas are constantly being tested; and that it is possible to criticise them or reinterpret the data.

Both in Liang et al.'s (2009) study and in the present one, the topic of tentativeness received the highest score of all six topics (15.59, 17.10 and 15.81 in the Turkish, Chinese, and American samples; 15.19, 14.41 for Groups 1 and 2 at the beginning of the course; Table 10). Apparently, many students appreciate that scientific knowledge can change, even though they have an unclear understanding of the mechanism through which changes to theories and laws operate.

While analysing the items individually, both studies found a disparity in responses to different questions. In both cases, the majority of students agreed that scientific theories are revised periodically and that they can be replaced. However, few students believed that a theory can change as a result of a reinterpretation of the existing data. What is more, the majority of students in both studies believed that if theories are based on precise experiments, they will not change in the future.

The analysis of responses to the open-ended questions allowed for the clarification of this apparent contradiction in the Likert scale items: several students that believed that scientific theories change also believed that the object under scrutiny also changes. Liang et al. (2009) do not make reference to this conception in their work, but they argue that many preservice teachers believe that technological advances that lead to new information are the only factor that plays a role in theory change. These ideas were also suggested in the present study. The finding that students attribute changes in science to different causes was first described by Aikenhead (1987) in a report of an analysis of more than 400 paragraphs written by students by way of an answer to questions about the tentativeness of science.

6.1.4. Students' views about scientific theories and laws

A common idea among laypeople is that scientific theories are inferior to laws and, thus, need to undergo a process that transforms them into laws. The implications of this misconception are that students end up believing that theories are tentative and have little empirical support, whereas laws are true and immutable (McComas et al., 1998; Lederman, 2007). This idea that, unlike laws, theories are arbitrary interpretations with little support constitutes fertile ground for charlatans that undermine scientific theories for their own personal interest, and without offering conclusive evidence in favour of wrongheaded ideas and/or products.

In both studies, this topic received the lowest score of all (9.28, 11.25, 9.75, out of 20, for the Turkish, Chinese, and American samples; 9.26 and 10.03 for Groups 1 and 2 at the beginning of the course). Liang et al. (2009) did not find any student with an informed view in this topic in the Likert scale items. On the contrary, in the present study the item that asserts that theories explain laws (Statement 3D, Appendix A) was correctly answered by approximately half the students. However, in the responses to the open-ended questions only one student explained with any depth this idea, whereas the rest of the students offered a naïve or transitional viewpoint. This suggests that students did not understand the item. Cronbach's alpha for this topic was quite low, mainly due to this statement, something that did not occur in Liang et al. (2009).

6.1.5. Students' views about the social and cultural embeddedness of science

Many students believe that scientists are isolated from society. This view feeds into the belief that scientists' work is objective and free from moral and social values. Likewise, it denies the possibility of criticising or questioning scientific activity.

In both studies, students showed for the most part transitional views of the relationship between science and society, and the scores for the Likert scale items were similar (10.71, 14.64 and 14.40 for the Turkish, Chinese, and American samples; 12.84 and 14.25 for Groups 1 and 2 at the beginning of the course). That scientists are not influenced by their culture and that all cultures carry out scientific research in the same way was a common idea among students. In spite of this, some students did use examples that exhibit an awareness of the social and cultural embeddedness of science, like that exemplified by the influence of war on research.

Similar views about the interaction between science and society, from both students and preservice teachers, have been reported in the literature, together with the difficulty inherent in changing them (Akerson et al., 2000; Abell et al., 2001).

6.1.6. Students' views about creativity and imagination in science

The view that scientists are objective and that all interpret phenomena in the same way leads students to ascribe to imagination and creativity and limited role, for instance, in the design of scientific experiments. It is a common student belief that logic is the only mechanism through which scientists come up with theories (McComas et al., 1998). Understanding the role that imagination plays in these processes constitutes a more accurate picture of scientists and opens the possibility that several different interpretations could be made from the same data. This, in its turn, could induce students to reflect on the role of evidence in the construction of scientific knowledge.

Science classes in general do not promote a view of science where imagination plays a role: laboratory exercises that students are familiar with are for the most part verification activities where a structured sequence of steps are followed to reach an already known result (McComas et al., 1998).

The mean scores for the Likert scale items for this topic (13.03 and 12.43 for Groups 1 and 2 at the beginning of the course) are slightly higher than those obtained by the American sample (11.59) in Liang et al,'s (2009) study and lower than the scores of the Turkish and Chinese sample (14.41 and 15.30 respectively). The majority of students, both in Liang et al.'s (2009) study and in the present one, acknowledged that imagination plays a role in science. However, almost all students believed that this role is limited to some aspects of scientific activity, such as the invention of new products or technologies, or the design of experiments. In responses to the open-ended questions students barely mentioned examples of the use of imagination, a finding that contrasts with the use of examples in other topics of the questionnaire. This finding suggests that this topic was not discussed explicitly in class.

6.1.7. Students' views about scientific methods

According to McComas (1998), the existence of a universal scientific method is one of the more widespread myths in science education. The most common belief states that there is a series of predetermined steps that lead scientists to true results.

The fact that many students believe that there is a single scientific method, and that following it leads to true and accurate results, contributes to a misinterpretation of disagreements among scientists: students tend to think this is due to incompetence, lack of knowledge, or to personal interests of scientists. The most widespread idea of a single scientific method also denies the role of imagination and creativity, the theory-ladenness of observation, and the subjectivity of scientists. There is also the risk that students might believe that any product tested with the aid of the scientific method is trustworthy and safe.

Liang et al. (2009) found notable differences among the samples. Chinese teachers exhibited a more developed view compared with their American and Turkish counterparts. In the present study, at the beginning of the course the scores of both groups (11.93 and 13.67 for Groups 1 and 2 respectively) were lower that those of American teachers (13.90). However, at the end of the course Group 2 improved noticeably (15.27), approaching the mean score obtained by Chinese teachers (15.90). In the present study, the proportion of students that answered correctly the statement concerning the use of different methods to carry investigations was higher than in all of Liang et al.'s (2009) samples. However, when responses to the open-ended responses were analysed, several students were found that interpreted 'methods' as laboratory techniques.

This finding has been previously reported in the literature, and it is due to the experience students have regarding scientific activity, which is almost always second-hand either in school or received from the mass media (Driver et al., 1996). Participants in this study were familiar with laboratory activities based on rigid guidelines on how to carry them out and how to report the results.

However, in spite of the fact that several students have this naïve view of the scientific method, other students did use more sophisticated examples, mainly from a particular topic seen in the classroom, such as the construction of the periodic table of the elements, the discovery of penicillin, and the photoelectric effect. These results differ from the ones found in the original study of Liang et al. (2009), in which almost none of the students answered the open-ended question with a sophisticated understanding (especially in the case of American and Turkish samples).

6.1.8. The effect of the course on students' views

Generally speaking, the course had little or no influence on students' views in Group 1. In an informal talk with the course's teachers, they emphasised that the course focused on the importance of the social context in scientific activity, something that was not reflected in the questionnaire's results. In Group 2, students' views changed on the role of imagination and creativity in science and the scientific method. According to informal comments made by teachers, these topics were studied in an explicit manner throughout the course, particularly the scientific method. However, other topics, like objectivity and the social and cultural influence on science, were touched upon but did not have the desired effect on students' views.

The first questionnaire was administered in the third and fourth class of the course to both groups. Given that the syllabus of the subject starts with these topics, they were already being taught when the questionnaire was administered. Consequently, in the first administration many students mentioned examples that had been discussed in class. This was particularly noticeable in the case of observations and inferences and the social and cultural embeddedness of science. The examples given by the students to illustrate observations and inferences were both diverse and used repeatedly by students, for the most part adequately. However, the use of these examples decreased in the questionnaire administered at the end of the course. Informed views in the open-ended questions also decreased while naïve and transitional ones increased (only in Group 1; Table 11). This could be due to students being able to remember, at the beginning of the course, ideas they had learned recently, but that they had already forgotten by the end of the course. This finding suggests that more discussion is needed about these topics: they need to be treated repeatedly throughout the course, in different contexts and not just at the beginning of the course.

In both groups, teachers used examples from the history of science to teach specific aspects of the NOS. The examples provided by students in the SUSSI suggest that this approach did have an impact on the way they see science. However, the fact that, at the end of the course, a smaller number of examples were given, or were applied inadequately, suggests that students had not assimilated their knowledge.

The focus on the history of science has been used with uneven results in previous studies. A common element in studies that have obtained more or less successful results is the explicit teaching of aspects of the NOS and the opportunity for discussing them provided to students (Solomon, 1992; Abd-El-Khalick and Lederman, 2000; Lin and Chen, 2002).

It has been suggested that one of the difficulties in the teaching of the NOS with the aid of the history of science is that teachers need to situate students in the historical context and avoid analysing scientific ideas through the lens of modern frameworks (Abd-El-Khalick and Lederman, 2000). In general, studies have shown that students change their views more readily of some aspects of the NOS than others, the more difficult being the subjective nature of science and the social and cultural embeddedness (Akerson et al., 2000). One of the more successful cases in the teaching of the NOS was adapted to a conceptual change model, in which students reflected on their initial views about science (Abd-El-Khalick and Akerson, 2004).

Besides the difficulties inherent in understanding ideas about the NOS, there are studies that suggest that students find it difficult to translate their ideas from one context to another (Abd-El-Khalick, 2001; Abell et al., 2001).

The difficulty to change students' views of the NOS is a common occurrence, since students have been exposed to inadequate views about science both at school and through the mass media (Abd-El-Khalick and Lederman, 2000).

Generally speaking, the results obtained with the SUSSI questionnaire confirm the findings of other studies. The majority of students has naïve views about the NOS and hardly changes their views after an educational intervention. When they do, the change is limited to only specific aspects and does not affect the overall view. Even more, in some aspects of the NOS in which the course appeared to have an influence, the changes were not long-lasting. These results corroborate the need for explicit teaching of the aspects of the NOS throughout the whole course and not only in a single unit.

6.2. Students' decisions—the Decision-making Questionnaire

It has been argued that having an adequate view of the NOS can help students make better decisions about science-related issues, particularly SSI (for example, see Driver et al., 1996). The decision-making about scientific issues is one of the main objectives of the scientific literacy. This has been one of the arguments in favour of the inclusion of the NOS in current science curricula.

Among the ideas about science that have been advocated as relevant to the successful resolution of an SSI are the ability to distinguish between theories and observations, between opinion and evidence; the capacity to assess the validity of evidence; comprehension of how scientific knowledge is generated; the skill to search for and assess sources of information; the ability to identify the agents involved in a dispute, as well as their views; and the evaluation of risk (Ratcliffe, 1996; Millar and Osborne, 1998; Osborne and Collins, 2000). However, so far findings about the influence that views of the NOS play in decision-making when faced with an SSI are inconclusive and, at best, indicate that the NOS plays a marginal role in decision-making. In spite of this, it has been postulated that an adequate knowledge of the NOS could help individuals to discriminate pseudoscientific arguments from scientific ones (Bell and Lederman, 2003). This claim, however, has not been corroborated by evidence.

Research about how knowledge of the NOS affects decision-making about SSI has not focused on the influence the SSI or the context exerts on the ideas individuals use to make a decision. This fact is surprising, given the results of research conducted by several authors on the difficulty of transferring ideas of the NOS to novel situations (Abd-El-Khalick, 2001; Abell et al., 2001) and on the influence that personal involvement and beliefs play in students' reasoning (Zeidler, 1997; Sadler and Zeidler, 2005).

In the present study, the use of ideas about the NOS by students was evaluated in several different contexts. Said contexts differed amongst themselves on the degree of knowledge students possessed about them, the degree of personal involvement with the issue, and the kinds of topics they made reference to—pseudoscience, SSI, and instances of well-established science. The ideas students used to make a decision in the different scenarios were compared in order to determine the influence of the context on the way views of the NOS were used in decision-making.

The following paragraphs will discuss findings from the decision-making questionnaires presented in the previous chapter.

6.2.1. Pseudoscience scenarios

In their everyday living individuals become involved in situations where pseudoscientific claims are a component. In many cases, these decisions relate to health issues, such as alternative therapies and some 'healing' or beauty products. It has been shown that many people tend to believe that these therapies are effective (National Science Board, 2002), especially when their advocates appeal to personal experience, as in the case of the testimonials of 'patients'. The popularity of these therapies lies mainly in the fact that they offer easy and quick solutions with no side effects with the concomitant sensation of control over the problematic situation (Lindeman, 1998).

Decisions about pseudo-scientific claims have a desired course of action that involves recognising these claims as fallacious and consequently rejecting them. It has been proposed that an adequate view of the NOS can contribute to decision-making concerning these issues (American Association for the Advancement of Science, 1993; Erduran, 1995; Smith and Scharmann, 1999; Kolstø, 2001; Bell and

Lederman, 2003), even though there is, at present, no evidence to support such a claim.

In the present study students' responses to three pseudoscientific scenarios were compared—miracle weight-loss pills, Aids denialists, and quantum medicine. These scenarios varied in the degree of students' familiarity toward and knowledge of these issues. The text of the three scenarios emphasised explicitly that scientists rejected the claims made by the manufactures of the pills, Aids denialists, and quantum doctors, advocates of their respective products and/or therapies.

Almost all students rejected or argued against the ideas of the Aids denialists and the weight-loss pills. In the present study students' knowledge of these issues was not evaluated. However, it is not inconceivable that students have more familiarity with both these topics, since nutrition and Aids are issues included in the curriculum and there is plenty of information in the mass media. In contrast to the responses to these two scenarios, students appeared to be more indulgent towards quantum medicine—a topic they knew nothing of. The importance of background knowledge in decision-making all three cases echoes the findings of Keselman (2004), who found that students with more knowledge of the Aids virus tend to reject myths about this disease.

Students relied on a variety of arguments to support their decision of whether to accept or reject the therapies or products on offer. These arguments differed from one scenario to another. The role of the context in students' decision-making begs the question of whether a sophisticated view of the NOS, complemented by an understanding of the criteria of demarcation between science and pseudoscience, would allow students to make correct decisions in a variety of contexts about which they have no knowledge.

In general, the justifications offered by students were short and superficial. In many cases it was evident that students ignored several of the arguments cited in the text. This selective and/or biased analysis of the information has been reported previously in the literature on the subject, and it has been found that individuals tend to ignore data that do not agree with their beliefs (Zeidler, 1997).

Bell and Lederman (2003, p. 370), having found that individuals with sophisticated views about the NOS do not make use of them when deciding, have argued that

> It is possible, perhaps even likely, that results of the suggested empirical studies [that delineate the role of the views about the NOS in decision-making] will not support the assumptions and hopes that many science educators hold for the nature of science. If this is the case, the science education community may be forced to decide between the empirical evidence of what supports decision making and what the science education community values.

In the three scenarios, several students used ideas included in the NOS category (Table 16) in order to justify their decisions. In this respect, it is notable that, in spite of the shallowness of their responses and the naïvety of their views of the NOS, none of the students that used ideas of the NOS in their decision accepted the therapies or products, This finding contradicts those of Bell and Lederman (2003), who found that there was no relation whatsoever between the ideas of the NOS used and decision-making (even though, in their case, they used as probes socioscientific issues), thus arguing for their inclusion in the curricula.

In the weight-loss pills and quantum medicine scenarios, caution due to the lack of evidence was the most widely used criterion from the NOS category. In the case of the Aids denialists, the NOS criterion most widely used was the endorsement/rejection by research and, to a lesser degree, appeal to authority.

In the literature there have been reports that caution due to the lack of evidence is a criterion used by students to evaluate information (Ratcliffe, 1999). The fact that students use this criterion does not mean that they possess a sophisticated view of the NOS, or that this criterion is the more adequate to make a decision. In fact, it is noteworthy that students used this criterion to justify their decisions when the text of the scenarios explicitly claimed that scientists oppose these therapies and products and have evidence against them. It is possible that a sophisticated view of the role of experiment and evidence in the construction of knowledge could facilitate the analysis of the information on the part of students and, as a consequence, improve the decision-making process (Kolstø, 2000).

On the other hand, in the Aids denialists scenario, several students used the endorsement/rejection by research as a decision-making criterion, and made reference to the fact that scientists have conclusive evidence that HIV exists and is the cause of Aids. The use of this criterion suggests some measure of familiarity with research on HIV or, at the very least, acceptance of the scientific information given in the text of the scenario. Other students relied more in the confidence they felt in doctors and scientists. Considerable knowledge of the issue was accompanied by a higher frequency of use of certain justified scientific ideas to back up a decision.

At present, the role of scientific knowledge in decision-making has been controversial, with some studies appearing to show that it is useful while others suggest that it only plays a secondary role in decision-making (for example, see Solomon, 1992; Sadler and Donnelly, 2006; Sadler and Fowler, 2006). In the present case, several students appeared to be influenced by their previous knowledge of HIV.

In spite of the fact that the quantum medicine scenario included an explicit reference to scientists' arguments against it, on the grounds that the theoretical underpinnings of quantum medicine are false, only one student made use of the criterion 'rejected by the research', while another relied on the authority of scientists and doctors. In this case, students were unaware of quantum medicine and, even though both the arguments of doctors and scientists and the theoretical framework that supports their views were included in the scenario, many students tended not to trust them or ignored their arguments.

The influence of the context and familiarity with the issue on students' decision-making was also evident in the remaining questions of the questionnaire. Students tended to believe that the mechanism of action of the weight-loss pills and the therapy advocated by the Aids denialists were false, or, at least, exaggerated. On the other hand, several students thought the ideas of quantum medicine were more believable and, accordingly, appeared to be more willing to accept them.

Besides evaluating the mechanism of action by recourse to different criteria, depending on the context, participating students tended to trust scientists more in the Aids denialists and the weight-loss pills scenarios than in the quantum medicine one.

In the latter, students claimed that scientists do not have the understanding to criticise the therapy, and that scientists do not accept it because they are not open minded enough or have conflicting personal interests. Several students argued that scientists should work together with the advocates of the therapy to confirm its reliability, in spite of the fact that scientists had argued that the theoretical basis of the therapy was false.

Criticisms directed towards scientists, in the case of the quantum medicine scenario, contradict the results obtained in the SUSSI questionnaire, where scientists were judged to be objective and methodical. These fragmented and inconsistent views of the NOS, together with their difficult to transfer nature, are a common feature and have been reported by other researchers (Lederman and O'Malley, 1990; Abd-El-Khalick, 2001; Hammer and Elby, 2001; Kolstø, 2001; Bell and Lederman, 2003).

Zeidler (1997) and Kolstø (2001) found out that, when students evaluate information, they usually do not concern themselves with the evidence supporting knowledge claims and tend to focus on evidence that confirms the views they already hold. It has also been found that when people are not aware of the biological mechanisms of health and disease, they place their trust 'on experiential and cultural knowledge and practices'. Individuals also find it hard to reconcile their systems of belief with scientific theories (Patel et al., 2000, p. 334). In this sense, Solomon (1992) has claimed that students should have at least superficial knowledge of a topic (in her case, SSI in the media) in order to be able to argue and take a stance; when students are not familiar with the topic, they tend to adopt negative or cautious attitudes towards science.

The idea that students should, at least, have an inkling of the issue in question so as not to mistrust science is somewhat worrying, since it is impossible to foresee which topics students will have contact with in the future. It is possible that if students understand how science works they will be less dependent on scientific knowledge about specific issues. However, due to the difficulty inherent in finding students with sophisticated views of the NOS, it remains to be seen whether this is the case. Students should understand the role of theory and evidence in science (Hodson, 1991) and develop ways to judge experts and sources of information, something that involves some awareness of social aspects of scientific activity (Norris, 1995; Driver et al., 1996). Aspects such as consensus, criticism, and peer review in science could also play an important role when students face unknown SSI about which a variety of opinions are available (Kolstø, 2000).

Apart from topics related to the NOS, students used other criteria to justify their decisions. In the case of the weight-loss pills, several students mistrusted the sellers and advocates of these kinds of products. These students commented that sellers lie or exaggerate the properties of their products. On the other hand, in the quantum medicine scenario only one student mistrusted the advocates of the therapy. In this case, students made a superficial risk/benefit analysis mainly based on the price of the drugs and the likely risks (or benefits) associated with the therapy. They made no reference to the evidence included in the text. In this scenario, some students asked for more information before making a decision. In the Aids denialists scenario, ethical values such as freedom of choice were considered to be important by several students. The diversity of strategies when dealing with science-related topics is a common finding in several studies (for example, see Kolstø, 2001; Jimenez-Aleixandre and Pereiro-Muñoz, 2002; Walker and Zeidler, 2007). However, the effect of different pseudoscientific contexts on students' use of ideas of the NOS in decision-making had not been previously explored.

Although the three scenarios had the same structure—the two opposing views are presented with an emphasis on scientists' counterarguments—the criteria employed in decision-making were very different. This significant effect of the context on decision-making—and justification—regarding pseudoscientific issues had not been reported in the literature and appears to depend on students' familiarity with the issue at hand. In contrast with the other two scenarios, in the quantum medicine one students felt non-scientific ideas were more credible than scientific ones. Neither did students apply consistently the criteria they relied on to evaluate the trustworthiness of the sources of information. This willingness to accept knowledge claims without questioning them appears to be a common practice (Phillips and Norris, 1999; Ratcliffe, 1999; Kolstø, 2001). However, it also appears to depend on the context.

At the end of the course, few students changed their opinion in these scenarios, and there was no clear trend in the direction of the changes that took place. This lack of a clear trend after an intervention designed to improve students' views of the NOS has also been reported by Solomon (1992). Unfortunately, at the end of the course students' views of the NOS did not improve noticeably, making it impossible to determine whether the NOS influences decision-making about pseudo-scientific issues. However, changes of opinion in the quantum medicine scenario seem to indicate that the use of certain criteria of the NOS—although unsophisticated—increases the chance that students will reject the therapy, since all students that shifted from acceptance to rejection or uncertainty ended up using criteria related to the NOS. On the contrary, the student that went from rejection to acceptance of the therapy used first a NOS criterion and then changed to a risk/benefit analysis argument.

In summary, results show that contexts played a considerable role in students' decision-making: in the scenarios students were familiar with, they tended to trust science and scientists. In contrast, when the scenario was unknown to them, they seemed more open to accepting pseudoscientific ideas and mistrusted scientists. All students that justified their decision by using ideas of the NOS rejected pseudoscientific claims. This could mean that a sophisticated view of how science works could help students to deal with pseudoscientific issues, even in novel contexts.

6.2.2. SSI scenarios

Frequently, the mass media bring us into contact with SSI. A characteristic of these issues is that they have neither a single, correct answer nor a pre-established method to solve them. In these issues, the scientific dimension constitutes only one part, since political, economic, social factors, and values, are also involved. In spite of the variety of factors involved in the solution of an SSI, it has been postulated that ideas about the NOS can help students analyse these issues and take a stance on them (Ratcliffe and Grace, 2003; Zeidler et al., 2009).

Up until now, many of the studies that have been conducted have dedicated themselves to assessing students' decisions and justifications in response to a narrow range of contexts, and only one has analysed in more detail the effect contexts have on students' responses. This study argued that the plausibility of the conclusions, the typicality of the issue (i.e., covered by the school curriculum), and familiarity with the issue affect the way in which students assess news briefs (Korpan et al., 1997).

In the present study, students engaged with three different SSI scenarios: mobile phones and health, foodstuffs from cloned cattle, and genetic modification in the prevention of mitochondrial diseases. These three scenarios differed in students' degree of involvement with the issue, as well as in their knowledge of it.

In the mobile phone scenario, students showed the highest degree of uncertainty in their decisions (as evidenced by the frequency of 'I don't know' responses). This uncertainty can also be seen in students' changes of opinion at the end of the course, which showed no clear trend in either way and were not drastic (that is, from 'Yes' to 'no' or vice versa). In contrast, in the modified humans scenario students appeared to be more certain in their responses (whether they were 'Yes' or 'No').

This finding merits attention, since mobile pones are much more close to students' everyday experiences, at least compared with genetic therapy. It is likely that in the modified humans scenario, being the farthest from their experience, students were able to make a decision (in reality, more an opinion than a decision) more readily because they did not take the issue seriously. In contrast, when their habits or activities are under scrutiny, they consider more factors when making a decision, making the decision-making process a more complex task. This conjecture is supported by the justifications given by students, as will be made clear in the following paragraphs.

Students' justifications in the case of all scenarios were brief and mostly superficial. For the most part, the views of the NOS used were naïve; scientific knowledge, superficial, erroneous, or misapplied; and the risk/benefit analysis perfunctory and ignorant of part of the information presented in the scenario. Generally speaking, students did not question the quality of the evidence provided. Similar inadequacies in students' answers and justifications have been reported in previous studies (Kolstø, 2001). In addition, the format of the questions could be responsible for students' superficial responses: they had to write their views in the questionnaire. In studies where students provided more sophisticated responses and a larger number of criteria in support of their decisions, group discussions were used—the exchange of ideas and the analysis of differing viewpoints enriched the decision-making process (Jimenez-Aleixandre and Pereiro-Muñoz, 2002; Zeidler et al., 2002; Ratcliffe and Grace, 2003).

Students used mainly two kinds of justifications belonging to the NOS: caution due to the lack of evidence and endorsement by research.

Caution due to the lack of evidence was a commonplace justification in all scenarios. This is a usual reaction towards SSI, since in many cases there is not enough information to make a decision. Students that used this criterion usually exhibited uncertainty before the situation put forward or rejected it. It is noteworthy that in the mobile phone scenarios none of the students that used the lack of evidence as a criterion claimed that mobile phones are harmful. However, several of the students that used this very same criterion did claim that they are not. This idea goes against the precautionary principle—students believed that mobile phones are safe unless proven otherwise.

When students were asked whether they believed that the evidence of the health effects of mobile phones and foodstuffs from cloned cattle was trustworthy, approximately half of the students claimed that it was indeed trustworthy because it had been obtained from reliable scientists or institutions. This 'analysis of the competence' of sources is quite frequent when addressing an SSI (Kolstø, 2001). Several reasons account for the remaining students' belief in the untrustworthiness of the evidence. Regarding mobile phones, students claimed that the evidence is inconclusive, that studies have not been performed in suitable biological models (for instance, genetic therapies have been tested in animals but not in human beings), or that the phenomenon in question is difficult to detect or scientists do not possess the necessary knowledge or made a mistake. In the cloned cattle scenario, students attributed their lack of trust in the evidence to the suspicion of possible economic and/or political interests on the part of scientists. These results suggest that the context plays a significant role in students' opinion of the trustworthiness of the evidence, since the criteria used to judge it were different in both cases.

The lack of trust in scientists—due to possible mistakes or ulterior motives—contradicts the views expressed in the SUSSI questionnaire, where the majority of the students judged scientists to be objective and adhered to the scientific method conducive to truth.

Arguments like lack of evidence and lack of trust in the evidence suggest, as in other studies, that many students believe that more research will produce a more certain answer (Driver et al., 1996; Albe, 2008). It has been suggested that when teaching the NOS, the role played by evidence—and the differences between 'science-in-the-making' and 'ready-made science'—need to be explored because they can help students understand why there is not enough evidence and why scientists disagree. On the other hand, students should also understand that sometimes they will need to make a decision even though they do not have conclusive evidence (Kolstø, 2000).

Another justification classified under the rubric of the NOS centred on the endorsement by science: in the cloned cattle scenario students claimed that they would be willing to eat foodstuffs from cloned animals because they had been endorsed by the scientific research.

It is noteworthy that only two students considered the disagreement between scientists as a criterion in making their decision, since this is a common element in SSI and was explicitly mentioned in the scenarios. This result contrasts with the those of other researchers, who found that disagreement among scientists was a crucial criterion in the evaluation of information (Kolstø, 2001).

When asked about the possible causes of disagreement among scientists in the cloned cattle scenario, students attributed it to scientists having doubts about the safety of the therapy or ethical and moral issues. None of the students considered that scientists could interpret data in different ways, which is consistent with the results obtained in the SUSSI questionnaire about the relationships between observations and inferences. Even though students did not justify their decision by reference to it, they appear to be able to recognise that disagreements among scientists are a possibility. This idea contrasts with their responses in the questionnaire that probes their views about science, where many claimed that scientists are objective and that their observations and interpretations of the same phenomenon would match each other.

Students also did not make reference to, as part of their argument, possible interests and biases in scientists—an idea that was used frequently in the pseudoscientific scenarios. When faced with a SSI, students must be able to decide whether they can trust the experts and the sources of information, and to achieve this they must be aware of the sociological dimension of science (Driver et al., 1996). Kolstø (2000) has suggested that the teaching of the NOS should emphasise the human aspect of science, that is, the processes of communication among scientists, the search for consensus, and peer review. He has also suggested that students must be made aware of the limits of science and its inherent values, such as 'suspension of belief'—where scientists postpone public judgement until more conclusive evidence comes along.

In spite of the fact that, supossedly, ideas about the NOS should inform individuals' decisions, its actual role is doubtful, given that results from previous studies are contradictory. On the one hand, Zeidler et al. (2002) have found that students' beliefs about the 'centrality of data', together with the ability to distinguish between a theory and an opinion, influence their decisions when faced with situations that challenge their beliefs. In contrast, Bell and Lederman (2003) found that ideas about the NOS among college teachers did not influence their decision-making in a variety of scenarios—teachers based their decisions on values and ethical and/or social considerations.

In the present study, ideas about the NOS, though superficial, limited, and naïve, did seem to play an important role that varied according to the context faced by students. However, due to the limitations of the study, students with sophisticated views of the NOS could not be compared with those with naïve views and it was impossible to establish whether a sophisticated understanding of the NOS informs decision-making. The course did not seem to have an effect on students' decisions on different scenarios.

Several students used scientific ideas to justify their decisions both in the mobile phone and cloned cattle scenarios. The first was closer to their experience—they use mobile phones frequently—whereas the latter is a topic that is touched upon superficially—if at all—at school and in the mass media. When students used scientific ideas (either correct or incorrect), they tended to conclude that mobile phones are harmful for one's health. The very same conclusion was reached in Albe (2008), where students used commonsense ideas about waves to explain why phones are dangerous. On the contrary, in the cloned cattle scenario students that used scientific ideas claimed to be willing to eat foodstuffs from these kinds of animals. None of the students that used scientific ideas paid attention to scientific ideas included in the scenarios that might have challenged their beliefs.

This range of ideas agrees with previous reports (Zeidler, 1997). Driver et al. (1996) have emphasised the role of scientific knowledge in decision-making about SSI, with the caveat that, in order to use it adequately, individuals must be capable of assessing its applicability, validity, and limitations with regard to the issue at hand. In the present study, students used scientific ideas both in the mobile phone scenario and in the cloned cattle one, although superficially, inadequately, and uncritically at best.

Up until now, whether scientific knowledge plays a role in decision-making about SSI remains controversial. Some authors suggest that having some knowledge of the topic helps students make up their minds (Keselman et al., 2004), while others argue that scientific knowledge plays a secondary role, particularly in the case of non-specialists (Sadler and Fowler, 2006). In the present study, scientific ideas played a role in decision-making in two of the contexts—even though they were not applied properly.

In contrast with what happened in the mobile phone and cloned cattle scenarios, in the modified humans scenario students failed to mention scientific ideas with which to justify their stance. This could have been due to two reasons: they either had no knowledge of the topic or other considerations (ethical or personal beliefs) played a bigger role. The latter has been advanced already by other authors: according to Fensham (2002; cited in Albe, 2008, p. 807) ‘decisions [on SSI] are based on an identification with the values as well as on personal criteria rather than on knowledge of scientific data.’

The role played by the availability of information in all three scenarios was quite distinct. In the case of mobile phones, several students made reference to the fact that publicising precautionary measures would scare people unnecessarily. In contrast, in the cloned cattle scenario several students claimed that consumers are afraid of these kinds of products only because they lack proper information. Finally, in the case of modified humans, students advocated information as a factor involved in decision-making.

Many students also used non-scientific arguments to justify their decisions. In the case of mobile phones, in contrast with the other two scenarios, several students relied on their personal experience in order to decide. Generally speaking, they argued that, since they did not personally know anyone who has been ill due to exposure to mobile phones, these devices ought to be safe. Albe (2008) studied also students’ responses towards the issue of mobile phones and noticed that personal experience influences their decisions. Zeidler (1997) considers this argument part of ‘fallacious thinking’, whereby students make generalisations out of inadequate data. It is well-known that when students are more emotionally involved in a situation, they tend to isolate their personal beliefs from scientific evidence that might contradict or challenge their beliefs—even to the point of ignoring it altogether in the decision-making process (Ratcliffe, 1999; Kolstø, 2001; Zeidler et al., 2002; Sadler and Zeidler, 2005). This discovery, furthermore, is supported by the fact that several students believe that recommendations issued to decrease mobile phone use are adequate but they would not comply with them, because doing so would imply changing their habits or because they are not aware of any cases of harm caused by mobile phones.

In the modified humans scenario, most students relied mainly on risk/benefit analysis. This argument led students to make both negative and positive decisions. Sadler and Fowler (2006) have pointed out that when students assess issues dealing with genetics, many of them tend to analyse them in terms of utility, evaluating the likely health outcomes derived from using those technologies. As in the pseudoscience scenarios, the analysis performed by students was mainly superficial and did not take into account many of the arguments included in the scenario. This incomplete analysis of the data is a common practice when assessing controversial situations. It has been reported in the past that people tend to ignore arguments that go against their beliefs (Chinn and Brewer, 1998; Phillips and Norris, 1999) or to be more critical of those that do not support them (Zeidler, 1997).

Another type of justification used in the modified humans scenario was ethical considerations that, since they involve values, produce a response characterised by support or rejection but not generally uncertainty. Being multifaceted problems, several different considerations need to come into play in students' decisions. Only one of the students that responded with ethical considerations changed his or her opinion at the end of the course (from 'I don't know' to 'No') but keeping the same justification (misuse of science). This suggests that values are crucial in determining the stance students will take. Issues having to do with genetics tend to generate responses connected with values, since individuals construe them as ethical problems in which moral, religious, and/or social norms are involved (Sadler and Fowler, 2006). Grace and Ratcliffe (2002) found also that values influence students' decisions on issues of species preservation.

The course does not seem to have had an effect on students' decisions, given that both their justifications and their decisions changed without showing any obvious trend. Solomon (1992) has also reported this effect in the past, after an intervention designed to teach the NOS. This suggests that, even if students' views of the NOS improved, they would still be unable—or find it difficult—to transfer these views from one context to another (Abd-El-Khalick, 2001).

In summary, contexts appeared to play a crucial role in determining which factors will influence students' decisions. In all scenarios, students ignored part of the information provided, especially if it contradicted of challenged their beliefs. Caution due to the lack of evidence was a widespread justification in all scenarios. However, when the context is near to students and involves an actual choice, as in the case of mobile phones, many exhibited more uncertainty when deciding and their personal beliefs appeared to influence their decision to a large degree. In contrast, when the situation is remote or unknown, as is the case of cloned humans, many students were more certain of their decisions, maybe because their analysis was not as deep as that of cases that hit them closer to home. In these latter SSI, their personal values or a superficial risk/benefit analysis also influenced their decision. Scientific ideas played a role in decision-making—albeit, for the most part, they were partial and inadequate.

These results suggest that conclusions drawn from several studies conducted about students' decisions are not generalisable to other, different contexts: the kinds of SSI, familiarity with scientific information relevant for engaging with the issue, students' prior misconceptions, their degree of involvement with the issue, and their values determine together how students will respond to an SSI. In this study is was not possible to explore whether a sophisticated understanding of the NOS actually helps students to make a decision, but even if students had such an understanding, the crucial factors that determine the character of a decision would vary depending of the context—each SSI is different and complex in its own particular way.

6.2.3. Well-established science scenarios

A sizeable number of investigations have been carried out about the decisions students make when faced with a socioscientific issue. However, in everyday life individuals constantly face decisions that involve science and that are not controversial—at least in any scientific sense. Among these issues are decisions about diet, exercise, smoking, and the use of medicines. There are few studies exploring whether an adequate view of the NOS and proper scientific knowledge influence these kinds of decisions.

In the present study, students engaged with three different well-established science scenarios: smoking, diet and diabetes, and self-medication. The majority of students classified themselves as non-smokers, led a healthy lifestyle, and did not approve of self-medication. The range of justifications offered in support of their decisions was even more limited than the range exhibited in the pseudoscience and SSI scenarios. The only justification under the umbrella of the NOS was the appeal to authority, used by some students in the self-medication scenario. Bell and Lederman (2003) also found ideas about the NOS do not play an important role in decisions about these kinds of well-established science scenarios.

On the other hand, in the smoking and the diet and diabetes scenarios some students used unjustified scientific ideas (for example, oft-repeated clichés that do not suggest students understand with any depth the scientific mechanism or idea that underpins the issues). In both cases, scientific ideas did seem to play a role in their decisions, since almost all students that used them (even in a superficial manner) claimed both not to smoke and to lead healthy lifestyles. In this case, given the widespread availability of information on these topics, it could be assumed that all students are aware of it—however, not all students cite it when justifying their decisions.

It has been found that a minimum level of knowledge about biology is needed to assess information and make a decision regarding health issues (Patel et al., 2000). A study that evaluated the smoking habits of pregnant women in the 1950s and 1960s—the same period when the first reports of health risks due to smoking were published—showed that those women with more years of schooling decreased their smoking habit compared with women with less schooling (Aizer and Stroud, 2010). Results suggest that information does play a role in decisions, even though in the present study it was not the only factor used by students to make a decision.

Many students used criteria unrelated to science to justify their decisions. In the self-medication scenario, the demand for more information upon which to make a decision and risk/benefit analysis were the most common justifications. On the other hand, interests and personal tastes predominated in the decision whether to smoke and lead a healthy lifestyle or not. Finally, in this last scenario other factors, such as lack of leisure time or funds, influenced students' decisions.

This usage of factors unrelated to science also took place in the study of Bell and Lederman (2003), where participants—even those possessing sophisticated views of the NOS—used factors like personal convenience, self-image considerations, and personal beliefs when addressing a scenario about the relationship between diet and cancer. Personal choice and personal convenience were the main justifications in a scenario about smoking and cancer (in which one of the scenarios used in the present study was based). It has been documented that, in many cases, the available information is not convincing enough to stop individuals from taking part in activities that put their health at risk—other factors, such as the subjective assessment of the likelihood of harm and its severity (Keselman et al., 2004), together with social and cultural factors (Patel et al., 2000; Fensham, 2002; cited in Albe, 2008), also influence decision-making.

It is possible that closeness to the situation might have influenced students' responses. The case of self-medication was merely hypothetical, whereas the other two scenarios involved real decisions. Unsurprisingly, at the end of the course students changed their decision more frequently in the self-medication scenario—a hypothetical case that did not question their habits—than in the remaining two scenarios. Habits like smoking or leading a healthy lifestyle and exercise are more stable and hard to change. The resistance to changing habits was expressed by students when asked whether—aware of the risks of self-medication—they would self-medicate in the future: several students admitted they would do it. In the case of diet and diabetes, several students claimed that they would only change their lifestyle—one they acknowledged was not healthy—if they became ill, whereas others said they would need more free time, money, or motivation to enact the change. In their study, Bell and Lederman (2003) also found that the resistance to changing habits did not lie in the perceived trustworthiness of the scientific evidence but in issues of convenience and will power.

When students were asked whether they believed that there was enough evidence to support the claims made by the different episodes and whether they thought the evidence was trustworthy, almost all agreed that there was enough and it was trustworthy. Students claimed that the evidence consisted mainly of the number of cases of either illness or death caused by self-medication, smoking, and diabetes.

Few students made references to research on microbial resistance to antibiotics or on the toxic compounds in tobacco—this suggests that students have only a perfunctory knowledge of these issues and the evidence involved. There were differences in the reasons students offered to ascertain the validity of the evidence: whether it is evident as a result of previous personal experience, there are statistical data, many tests have been conducted, and the tests were conducted by experts.

In this case, almost all students tended to believe both the scientific evidence and the experts, in contrast with what happened with several students in the pseudoscientific scenarios, especially in the case of quantum medicine. In the SSI scenarios, the decisions of many students were determined by caution due to the lack of evidence. However, in the well-established science scenarios, where there is a large amount of evidence in support of the claims, students did not use it as a decision criterion.

6.2.4. Patterns of response in the different scenarios

As has been discussed previously, students used different kinds of justifications to support their decisions, and these justifications depended on the context. However, by using a two-step cluster analysis a certain degree of consistency was found in the way each student solved the pseudoscience and SSI scenarios.

Students clustered in two groups: the first one used more scientific ideas and about how science works (caution due to the lack of evidence, lack of trust in non-scientific agents, endorsement/rejection by research), whereas the second used other kinds of analysis related to the lack of information, such as risk/benefit analysis, appeal to authority, and caution due to the lack of evidence. These findings suggest that a high proportion of students consistently used criteria related to science and knowledge in order to solve SSI and pseudoscience scenarios. On the other hand, another group of students consistently used another set of criteria related to the lack of information.

Very few studies have looked at patterns of response when students face different scenarios. Differences in the degree of similarity among the scenarios used and the category-building strategies make it difficult to compare results across studies. The present study used diverse kinds of scenarios and a system of categories independent from those of other published studies.

Bell and Lederman (2003) used different contexts in their research, even though—in their analysis—they did not emphasise the influence contexts exerted on decision-making. They found common strategies or patterns of reasoning used by the participants when faced with different scenarios: consider the evidence, conservatism (maintaining status quo), risk/benefit analysis, cost-benefit analysis, values-based. The authors did not explain whether participants used these reasoning strategies consistently in all scenarios—a noteworthy result, if found, given the thematic differences among the scenarios. In this study, the authors emphasised the role of evidence in their analysis, which allows for comparisons with the present study where a sizeable number of students used the evidence (or the lack of it) as a criterion in their decision-making.

On the other hand, Sadler and Zeidler (2005) defined three different patterns of response of students: rationalistic, intuitive, and emotive. As defined by them, the rationalistic category is very broad and includes the analysis of the rights and responsibilities of patients subjected to genetic therapy, evaluation of alternatives, and risk analysis. Students' responses were given to six scenarios that presented controversies about genetics and were very similar to each other. The authors mentioned that students tend to use one or more kinds of reasoning when responding to the issues. This model is limited by the fact that it does not explore how students use their scientific knowledge or their ideas about the NOS and introduces little variation among the contexts presented, making it likelier that participants will resort to similar arguments in all cases.

6.2.5. The influence of the context on the use of ideas of the NOS in decision-making

In the present study, students used some ideas of the NOS. The degree of sophistication of these ideas was variable, but they were generally superficial and naïve. The context was a determinant factor in the use of ideas of the NOS in decision-making. These ideas were mainly whether the arguments provided were endorsed/rejected by research, the role of evidence, appeal to authority, political and economic interests of scientists, and disagreements among themselves. In the scenarios about pseudoscience students used a wider variety of ideas of the NOS than in SSI scenarios. In the scenarios about well-established science students almost did not use these ideas to justify their decisions.

In the case of pseudoscience scenarios, ideas of the NOS did play a role in the rejection of claims, even when students did not possess sophisticated views. To the best of my knowledge, so far there is no study that has compared, in-depth, how students' ideas of the NOS influence their decision-making process regarding pseudoscientific issues. Studies that have been conducted about this topic assess students' views and determine whether those that have sophisticated views are less prone to believe in pseudoscientific beliefs like Area 51, magnet therapy, or extrasensory perception (Johnson and Pigliucci, 2004). Up until now, a relationship between views of the NOS and propensity to believe in pseudoscience has not been found.

The limitation of the study centred on not being able to compare students with sophisticated views of the NOS. However, it is likely that these would have contributed to the improvement of the decision-making process: students would understand better the role of evidence, the causes of disagreements among scientists, and the tentativeness of scientific knowledge, among other ideas.

The fact that ideas of the NOS assist in decision-making contradicts the findings of Bell and Lederman (2003), who found that ideas of the NOS play, at best, a marginal role in decisions about SSI.

In the SSI scenarios, ideas of the NOS, mainly caution due to the lack of evidence, were used fairly frequently. However, in this case the influence on students' decisions had no clear trend. SSI are complex, and their resolution requires much more than sophisticated ideas about the NOS. However, the fact that students considered them at all in the resolution of the SSI indicates that they are a useful tool in the analysis of these kinds of issues.

The findings on the use of ideas of the NOS when addressing pseudoscientific issues and SSI advocate their inclusion in science curricula. The results of teaching the NOS have not been encouraging thus far—students' views continue being naïve and persistent. However, their role in decision-making and the opportunity they represent for students to apply them to a wide variety of contexts merit the search for new teaching and assessment strategies of the central aspects of the NOS.

Chapter 7. Conclusions

In this chapter, the main findings are recapitulated and re-examined in the light of the original research questions. Following that, a consideration will be made of some of the strong points and limitations of the study. Later still, a few of the likely implications of the findings—for researchers, curriculum developers, and teachers—will be discussed. A final section will suggest further lines of research stemming from the conclusions of the present study.

7.1. Main findings

The research questions that guided the realisation of this project where:

- What ideas about the NOS do students draw upon when asked to make a decision on a socio-scientific issue, a well-established scientific issue or pseudo-scientific issue?
- What differences exist in the ideas about NOS that students draw upon when making a decision on controversial socio-scientific issues, well-established scientific issues or pseudo-scientific issues?
- To what extent are students' ideas about the NOS associated with the acceptance or rejection of the option presented?
- To what extent do students' ideas about the NOS change after taking a course focused on the relationships between science and society?
- To what extent do ideas about the NOS that students draw upon when making decisions on socio-scientific issues, well-established scientific issues, and pseudo-scientific issues change at the end of the course?

In this next section, the main conclusions drawn from the data are discussed in the light of the above questions.

7.1.1. What ideas about the NOS do students draw upon when asked to make a decision on a socio-scientific issue, a well-established scientific issue or pseudo-scientific issue?

Students used a wide range of justifications for their decisions in the scenarios. Some of these justifications were related to the NOS, whereas others were germane to scientific knowledge of the topic and others to non-scientific factors. Generally speaking, students made reference—when justifying their decisions—to factors related to the NOS only in passing, showing little to no in-depth understanding of the scientific enterprise.

Among justifications related to the NOS were included criteria such as a topic being endorsed/rejected by current scientific research, the role of evidence in decision-making (exemplified by an attitude of caution due to the lack of evidence), the appeal to scientific authority (and, consequently, trust in scientists), and political or economic interests of scientists, together with disagreements amongst themselves.

Besides ideas of the NOS, students justified their decisions by reference to other kinds of ideas. Among these were scientific ideas (adequate and inadequate, as well as with varying degrees of depth), request for more information, trust or lack of trust in other sources, trust in personal experience, ethical considerations—such as personal beliefs, individual freedom and fear of misuse of science—personal interests or preferences, risk/benefit analysis, evaluation of different alternatives and other, more practical factors such as lack of time or money.

7.1.2. What differences exist in the ideas about NOS that students draw upon when making a decision on controversial socio-scientific issues, well-established scientific issues or pseudo-scientific issues?

There were differences in the range of ideas used by students in each of three kinds of scenarios (pseudoscience, SSI, and well-established science). What is more, there were also marked differences in the range of ideas used among scenarios of the same kind. Results suggest that students' knowledge of, degree of familiarity with, and personal involvement with a particular issue affected in an important way the resolution strategies they brought to bear on the issue.

In pseudoscientific scenarios, particularly in the weight-loss pills and quantum medicine scenarios, the most frequently used idea of the NOS as a justification was caution due to the lack of evidence regarding the effectiveness of these therapies. On the other hand, in the case of the Aids denialists, students made reference to the endorsement/rejection by research on HIV and appealed to the authority of scientists.

Besides ideas related to the NOS, in the case of weight-loss pills, mistrust towards the companies that make and sell them was frequent among students. This argument was quite uncommon in the quantum medicine scenario, where many students based their decision on a risk/benefit analysis. In the case of the Aids denialists, some students also used as justifications their knowledge (or scientific ideas) of the topic and the argument that claims that everyone is free to decide whatever is best for oneself (individual freedom).

Broadly speaking, in the pseudoscience scenarios, when students had some previous knowledge of the issue—such as in the case of Aids and diet—they used a higher proportion of ideas about science, the role of evidence, endorsement of scientific research, and appeal to authority. When asked, students showed distrust towards the arguments offered by the advocates of the therapies and products but trust towards scientists. In contrast, when students were unfamiliar with the topic—such as quantum medicine—the majority of their decisions were based on non-scientific criteria and caution due to the lack of evidence. In this last case, many students appeared to be more open to accepting pseudoscientific arguments, while describing scientists as close-minded, ignorant, or biased by personal interest whenever criticisms against quantum medicine were raised.

In stark contrast to the variety of justifications related to the NOS used in pseudoscientific scenarios, in SSI scenarios students used a more limited range of ideas. The argument for caution due to the lack of evidence prevailed. However, in the cloned cattle scenario several students mentioned also the endorsement/rejection by research as a relevant factor in making their decision.

Only two students thought that disagreement amongst scientists could be used as a guiding criterion in their decision. When asked about the causes of these kinds of controversies, students attributed them to lack of objectivity on the part of scientists, to their religious or ethical ideas, or to economic interests.

Both in the mobile phones and the cloned cattle scenarios, students used scientific ideas (for the most part, superficial or mistaken), in contrast to what happened in the modified humans scenario—where there was no mention of these kinds of ideas. In this scenario, risk/benefit analysis was the most frequently used justification. In the mobile phone scenario, personal experience also played a role in decision-making.

In the case of SSI, it also was noticeable that the degree of familiarity or involvement with an issue affected students' decision-making strategies. In the mobile phone scenario—a device students use in an everyday basis—personal experience played an important role, together with scientific ideas concerning the potential harmful effects of this technology. In the scenario about cloning—a topic students are only slightly familiar with from biology lessons and the mass media—several students also used scientific ideas and the endorsement of scientific research. In contrast, in the modified humans scenario—one far from students' experience—many students resorted to a risk/benefit analysis (that failed to consider the arguments provided in the text) or relied for their decision on values and personal beliefs.

When conducting a cluster analysis of the range of justifications provided by students for the pseudoscience and SSI scenarios, two main groups were identified. The first group of students appeared to base their decisions on scientific ideas (about the NOS and scientific concepts) and the lack of trust on non-scientific agents, whereas the second group apparently relies more on other kinds of factors, such as risk/benefit analysis and the demand for more information. Caution due to the lack of evidence appeared to be a common argument in both groups.

In the well-established science scenarios, the only idea of the NOS used was the appeal to scientific authority, mainly in the case of self-medication. This scenario was the most distant from students' everyday experience—even though students confessed to self-medicating—since it posited a hypothetical case.

In the smoking and diet and diabetes scenarios—where students had to provide an answer about their personal habits—several students made reference only superficially to scientific ideas. Other factors unrelated to science had more weight in students' decisions in these types of scenarios, such as personal interest or taste or practical considerations, such as unavailability of time and/or money.

When asked whether the evidence provided was trustworthy and why, all students agreed that it was, adding three reasons why it is so: it comprises statistical data, it was obtained by experts, and personal experience supports what the evidence says. These results contrast with students' beliefs on quantum medicine, where many students trusted the therapy in spite of the fact that no statistical data was provided and it was explicitly claimed that the experts—scientists in this case—opposed it. In these scenarios, students also ignored the values and/or personal interests of scientists. Neither did they question their own knowledge, as in the case of SSI.

7.1.3. To what extent are students' ideas about the NOS associated with the acceptance or rejection of the option presented?

Apparently, ideas about the NOS proved to be useful for students in the case of all pseudoscientific scenarios, where it is highly desirable for them to reject the therapies and products. None of the students that used these ideas to justify their decision accepted to try out the therapies or drugs based on pseudoscientific principles: they rejected them outright or exhibited uncertainty towards them. The number of students that used ideas about the NOS in each scenario did vary, but in all cases these ideas led students to reject pseudoscientific claims. This finding suggests that, at least in the case of pseudoscience, ideas of the NOS are useful to assess claims, whether or not students are familiar with the context or the issue.

When students used their scientific knowledge to justify their decisions in pseudoscientific scenarios, the outcomes were more varied: some students ended up giving a chance to the therapies, mainly due to the inadequate application of scientific ideas. Responses were also diverse when students used other non-scientific factors as justification. In the quantum medicine and Aids denialists scenarios, almost all students willing to try them out relied on these kinds of factors as decision-making criteria (mainly risk/benefit analysis in the quantum medicine scenario and the appeal to personal freedom in the Aids denialists one).

In SSI scenarios, where there is no clear response, ideas about the NOS—mainly caution due to the lack of evidence—led students to decide to reject or remain uncertain in all three scenarios. The one exception to this occurred in the cloned cattle scenario, where some students agreed to consume foodstuffs from this kind of animal, arguing that they were endorsed by scientific research.

The use of scientific ideas varied from one SSI scenario to the other: in the mobile phone scenario almost all students that used these ideas believed that these devices cause health-related problems, whereas in the cloned cattle scenario the use of scientific ideas led students to accepting the foodstuffs from these animals. When students relied on non-scientific factors to make their decisions, they appeared to be more accepting of mobile phones (through an appeal mainly to personal experience). This did not happen in the case of products derived from cloned cattle, where uncertainty, acceptance, or rejection were used to a similar degree by students that used non-scientific factors as decision-making criteria. In the modified humans scenario, justifications based on values led students to reject or be uncertain about the situation.

In these SSI scenarios, consideration of the evidence was a common factor. This argument led students to reject or be uncertain about the situation. However, the use of other ideas of the NOS was very limited and dependent on the context.

In well-established science scenarios, particularly those about smoking and diet, almost all students that used scientific ideas (though mainly unjustified) to support their decisions also claimed to lead more healthy lifestyles. On the other hand, when students used other factors as decision-making criteria (such as personal taste or practical reasons), there was no apparent trend in their decisions. In the self-medication scenario almost all students, independently of what their justification was, rejected this practice.

7.1.4. To what extent do students' ideas about the NOS change after taking a course focused on the relationships between science and society?

The majority of students exhibited naïve views of the various topics of the NOS assessed by the SUSSI questionnaire. In this questionnaire, open-ended items helped clarify responses given by students.

Regarding observations and inferences, the predominant view was that scientists are objective and that, when scientists make different observations, it was because scientists conducted experiments differently or made experimental mistakes. Many students conceded that theories can change, but many also attributed this to changes in the object of study: students believed that if experiments are conducted properly, theories will not change. The relationship between theories and laws received the lowest score of all the questionnaire's items: all students chose to believe that, when verified, theories become laws. Students exhibited transitional views of the social and cultural embeddedness of science, since they generally disagreed with the idea that science is influenced by culture. However, they admitted that certain social events (like epidemics and wars) can affect scientific research. The role of creativity and imagination, in students' thinking, was restricted to certain processes of scientific research like the design of experiments. Finally, many students conceptualised the scientific method as a series of steps that lead to true results.

The course did not significantly influence the views of students in group 1, but it did influence the views of students in group 2 regarding the role of creativity and imagination in science and the scientific method. These topics were explicitly dealt with in the first weeks of the course (before the application of the first questionnaire) and students used examples learned in class. Like in the case of the difference between observations and inferences, students used examples. However, the number and variety of these decreased at the end of the course and their views shifted to the more naïve end of the spectrum. These findings suggest that students forgot what they had learned in the first part of the course.

7.1.5. To what extent do ideas about the NOS that students draw upon when making decisions on socio-scientific issues, well-established scientific issues, and pseudo-scientific issues change at the end of the course?

The Science and Society course does not appear to have affected students' responses and decisions, given that neither the changes of decision nor the justifications offered at the end of the course exhibited a clear trend. The number of students that used ideas of the NOS, scientific ideas, and other factors to make their decisions were similar before and after the course in all scenarios.

7.2. Reflections on the study

In the next few paragraphs some of the strengths and limitations of the study are discussed. The recognition of such limitations informs a subsequent section in which lines for further research are suggested.

In this study, it was possible to have access to a large sample of students (n=128) and, consequently, design and use nine different scenarios with which to assess the influence of different pseudoscientific, SSI, and well-established science topics. This variety of contexts resulted in a considerable richness of data, which itself allowed an in-depth analysis and the generation of classification categories. Access to a large sample of students also minimised the effect associated with sample mortality—students that did not completed the second questionnaire, particularly from Group 1.

The design of the decision-making questionnaires was such that, besides assessing the justifications for students' decisions, it explored in-depth their ideas about the proposed topics, about scientists, and about the role of evidence. This information proved to be very valuable because it allowed the exploration of ideas about the NOS that were not covered by the SUSSI questionnaire.

One of the main limitations of the study related to the lack of students with sophisticated understandings of the NOS against which to compare students' responses to the decision-making questionnaire. Unfortunately, only a few students at the end of the course improved their views of one or two aspects of the NOS (mainly concerning the scientific method and the role of creativity and imagination in science), but this did not cause significant differences in students' decision-making process at the end of the course.

An inherent limitation of the design of these kinds of studies is that, by using hypothetical cases, they end up assessing students' opinions but not their actual decisions. In this study, students only engaged with three situations that affect their everyday lives: the use of mobile phones, diet, and smoking. The remaining cases were hypothetical and, even though there is a chance that students will be forced to deal with them at some point, the decisions they made in these scenarios could have been lightly considered, since they are of no real consequence to them.

Another factor to keep in mind when considering the present study is that it did not assess explicitly the degree of familiarity students had towards the different issues. The effect of students' prior knowledge of the issues was evident in their responses, since they turned to different ideas when they had no previous knowledge of a topic.

In this study, the degree of sophistication of students' responses was not evaluated. A study of this kind would help distinguish with more precision students' range of arguments, while providing interesting data about the different kinds of decisions students make when using sophisticated ideas of the NOS compared to when they use naïve ones. Additionally, such a study would have provided the opportunity to distinguish between students that use adequate or inadequate scientific ideas and those that use fallacious thinking. However, this analysis is beyond the scope of the present study.

In a study of this nature, it would be ideal to have a valid instrument capable of assessing a greater variety of aspects of the NOS. The SUSSI questionnaire does not assess, for instance, aspects of the sociology of science—apart from social and cultural embeddedness—such as the role of consensus, peer review, and the importance of criticism in the construction of knowledge. These ideas were used in a perfunctory manner by students when making decisions, and it would be fruitful to be able to assess them with the aid of an independent questionnaire so as to determine whether these ideas are transferable across contexts.

7.3. Implications for science education

7.3.1. Implications for research in science education

There have been numerous studies made about the students' decision-making processes. These studies follow very diverse approaches and focus on issues such as students' argumentation strategies, their knowledge, how they evaluate the evidence, and how they use ideas of the NOS, among others. The majority of these studies use one or two different contexts, and few have used several. Of these last, fewer still have addressed the influence that the context has on the strategies students employ to deal with decision-making.

Given the important role played by the context, as suggested by the present study, it is crucial that research in the field take into account students' familiarity with the topics, their prior knowledge, and how likely it is that students will face the situation proposed, since these factors affect students' decision-making strategies. These considerations will be relevant when considering the limitations of generalisations drawn from the particular findings.

7.3.2. Implications for curriculum developers

Equipping students with tools they can use in their everyday lives is one of the objectives of scientific literacy, adopted by a number of educational policy documents and curricula at all levels of instruction in several countries. Scientific knowledge is too vast to be covered in school and, for the most part, it is impossible to cover the content students might need in the future to make informed decisions or to know which problematic issues they are likely to face. It has been proposed that having a sophisticated understanding of the NOS can help students make decisions about a variety of contexts, even though they might not have all the pertinent scientific information.

The results of this project suggest that views of the NOS do play a role in students' decision-making—especially in the case of pseudoscientific issues—and helped students to make better, more informed decisions. Incorporating aspects of the NOS suitable for developing sophisticated views in students could have a positive outcome on not only their decision-making processes in school, but outside of it as well. It is also possible that a sophisticated understanding of the NOS could allow students to understand better the demarcation criteria between science and pseudoscience and, consequently, stop them from being victims of charlatans willing to put them at risk.

Aspects of the NOS should permeate the curricula of all science subjects and be present in a variety of topics all through the school year, at levels of schooling. It is well known that—as evidenced in the present study—views of the NOS are hard to transfer across contexts and change. An adequate understanding of the NOS should not only include epistemological aspects, but also sociological ones, since some students use these ideas in their decision-making, even if naïve.

7.3.3. Implications for practise

The results of this project have implications for the improvement of teaching practices in the science classroom.

In light of the persistent nature of naïve ideas about the NOS, as evidenced by the SUSSI questionnaire, and how difficult students find it to transfer their ideas of the NOS across contexts, it seems advisable that teachers include these ideas in topics throughout the school year. These ideas, as has been shown in other studies, need to be explicitly taught and teachers should invite students to assess their own views and contrast them with the new ideas.

It would be useful to incorporate into science classrooms SSI, since students face them in their everyday lives and they are difficult to resolve adequately. These topics must be thematically broad and provide students with a full range of situations where they can explore their decision-making processes through different strategies. The role of teachers would be then to provide students with the necessary tools to assess the information presented, even that that goes against their beliefs—and that students tend to ignore.

7.3.4. Implications for teacher professional development

SSI are multifaceted problems that not only involve scientific knowledge, but political, economic, social, and ethical considerations. Teaching these topics, together with sophisticated views of the NOS useful as tools in decision-making, requires that teachers become aware of the complexities of the issues involved and that they learn to assess them from different standpoints.

One of the challenges for teachers that attempt to teach SSI would be accepting that not all decisions must be driven by scientific ideas, but by other factors that might have more weight in students' decisions, depending on the context. These varied points of view can also be valid and the role of teachers would be to teach students to justify their stance and to remain open to multiple points of view that may inform their own views.

So far, the inclusion of these topics in curricula has been peripheral and teachers appear to have no experience about how to tackle them in the classroom. If they are to be included in science curricula, adequate teacher training programmes would need to be developed where teachers 1) develop their views of the NOS and 2) learn and apply diverse strategies to the analysis and resolution of SSI in teaching settings and conditions.

Finally, the inclusion of pseudoscientific issues in classrooms would introduce students to the demarcation criteria that separate science from non-science and teach them how to evaluate claims and make informed decisions. In order for these skills to be taught, teachers in their turn need to be able to apply these criteria. It is known that many science teachers believe in pseudoscientific claims, so teacher training programmes where teachers can learn how to teach to students the skills and knowledge necessary to assess these kinds of claims would first need to address teachers' misconceptions.

7.4. Further research

This study leaves unanswered the question of whether students with sophisticated views of the NOS would use the same criteria used by the participants of the present study to make a decision. For this reason, it is suggested that the next step in the research should be assessing, and comparing, the decision-making processes of individuals with sophisticated understandings of the NOS and determining the usage of these ideas in decision-making in different contexts.

Results of this study suggest that many students did use ideas of the NOS to decide about pseudoscientific scenarios. However, this is barely the first finding worth exploring in more depth. The design of a number of different scenarios—where the degree of students' familiarity and prior knowledge towards the issue presented—and of questions that explore in more depth the ideas students use to decide, as well as their opinions about evidence and the different agents would expand the results of this study.

The present study was of an exploratory nature, and responses were categorised according to their thematic content. However, their quality was not determined. That is why it is necessary to conduct a deeper study that compares the quality of students' responses to different contexts. This study would require data collecting strategies different from the ones used in the present study, since limitations associated with students' writing skills and time constraints could have impacted negatively on the quality of the responses.

Finally, in another area of research, in order to assess views of the NOS in the context of decision-making, it is necessary to have a trustworthy, reliable, and validated assessment instrument that covers the social aspects of science. A study that develops and validates such an instrument would be of great help in the research on views of the NOS in decision-making.

Appendix A. SUSSI Questionnaire

Student Understanding of Science and Scientific Inquiry Questionnaire

Please read EACH statement carefully, and then indicate the degree to which you agree or disagree with EACH statement by circling the appropriate letters to the right of each statement (SD= Strongly Disagree; D= Disagree More Than Agree; U= Uncertain or Not Sure; A= Agree More Than Disagree; SA= Strongly Agree).

1. Observations and Inferences

A.	Scientists' observations of the same event may be different because the scientists' prior knowledge may affect their observations.	SD	D	U	A	SA
B.	Scientists' observations of the same event will be the same because scientists are objective.					
C.	Scientists' observations of the same event will be the same because observations are facts.					
D.	Scientists may make different interpretations based on the same observations.					
With examples, explain why you think scientists observations and interpretations are the same OR different.						

2. Change of Scientific Theories

A.	Scientific theories are subject to an on-going testing and revision.	SD	D	U	A	SA
B.	Scientific theories may be completely replaced by new theories in light of new evidence.					
C.	Scientific theories may be changed because scientist reinterpret existing observations.					
D.	Scientific theories based on accurate experimentation will not be changed.					
With examples, explain why you think scientific theories change OR do not change over time.						

3. Scientific Laws vs. Theories

A.	Scientific theories exist in the natural world and are uncovered through scientific investigations.	SD	D	U	A	SA
B.	Unlike theories, scientific laws are not subject to change.					
C.	Scientific laws are theories that have been proven.					
D.	Scientific theories explain scientific laws.					
With examples, explain the difference between scientific theories and scientific laws.						

4. Social and Cultural Influence on Science

A.	Scientific research is not influenced by society and culture because scientists are trained to conduct pure, unbiased studies.	SD	D	U	A	SA
B.	Cultural values and expectations determine <u>what</u> science is conducted and accepted.					
C.	Cultural values and expectations determine <u>how</u> science is conducted and accepted.					
D.	All cultures conduct scientific research the same way because science is universal and independent of society and culture.					
With examples, explain how society and culture affect OR do not affect scientific research.						

5. Imagination and Creativity in Scientific Investigations

A.	Scientists use their imagination and creativity when they collect data.	SD	D	U	A	SA
B.	Scientists use their imagination and creativity when they analyse and interpret data.					
C.	Scientists do **not** use their imagination and creativity because these conflict with their logical reasoning.					
D.	Scientists do **not** use their imagination and creativity because these can interfere with objectivity.					
With examples, explain why scientists use OR do not use imagination and creativity.						

6. Methodology of Scientific Investigation

A.	Scientists use a variety of methods to produce fruitful results. [Suggested revision: Scientists use different types of methods to conduct scientific investigations.]	SD	D	U	A	SA
B.	Scientists follow the same step-by-step scientific method.					
C.	When scientists use the scientific method correctly, their results are true and accurate.					
D.	Experiments are not the only means used in the development of scientific knowledge.					
With examples, explain whether scientists follow a single, universal scientific method OR use different types of methods.						

Appendix B. Decision-making questionnaires

Weight-loss pills

Carolina was worried. The previous term's heavy workload had left her with little time to exercise—she had spent most of her time studying at the university, eating whatever was available and, consequently, she had gained quite a few pounds. Her summer break at the beach was just around the corner and her favourite bathing suit no longer looked good on her.

One night, unable to sleep, she turned on the telly and—providentially—happened to find a way out of her worries. The host of an infomercial, a relatively famous actor, was saying: "The effectiveness of Demogras, destroyer of fat, has been scientifically proven. Once your cells perceive the conjugated linoleic acid, they will instantly start rerouting fat out of your body. Instead of sending it to be stored in places that grow to become a pot belly, fat is directly sent to mitochondria to be used up as cellular energy, that is, as energy for living. The ingredients in this product are absorbed by the glandular system, restoring its proper function and sending signals to the immune system to make it work faster."

Before the infomercial was over, some thin and fit people appeared on camera vouching for the benefits of the product, while before-and-after images of them showed amazing results. The next day, Carolina went out, bought some Demogras, and immediately started taking it.

When Carolina's friend, Rebeca, found out that her friend was taking pills to lose some weight, she told Carolina that she had read a newspaper article where several doctors claimed that products like Dermogras didn't work and that infomercials exaggerated the supposed benefits of the products they advertised. The article went on to say that scientists dedicated to developing new drugs take several years to gather reliable evidence about the drugs before making them available to consumers. Scientists also test the efficacy and safety of drugs thoroughly; tests the pills Carolina bought most likely didn't even go through.

Carolina wasn't quite convinced of Rebeca's warnings after talking with her.

1. Would you recommend the product to Carolina? | Yes | No | I don't know |
2. Why?
3. What do you think about the information given by the TV ad about the way the product acts in the body?
4. Why do you think that many of these infomercials claim their products have been scientifically proven?
5. What does it mean to you that a product has been scientifically proven?
6. Why is it important to have scientific evidence to back a product?
7. What would be in this case valid scientific evidence?
8. Have you used or would you use some of these products? What would you consider to choose one product?

Quantum medicine

Imagine that a relative of yours has been diagnosed with an incurable heart disease. According to the doctor's opinion, the disease is manageable with lifelong medication. This particular medication, however, is expensive and has some side effects, but the doctor strongly believes that not taking it endangers the patient's life.
While looking for other options for treatment, you find a new therapy called SCIO that is based on the principles of quantum medicine. To start with, the patient is first connected—via electrodes placed in his or her legs, arms, and head—to a bio-resonance and bio-feedback device that measures the frequencies of each and every cell in the patient's body and identifies which ones are suffering from some kind of imbalance. The treatment consists of restoring each cell to its natural frequency, initially imbalanced by stress, a poor diet, lack of exercise, or emotional problems. People that have undergone the therapy claim that it has cured their ailments. The device's inventor, Doctor William C. Nelson, has studied and taught in various universities and holds PhDs both in quantum physics and electrical engineering. He also travels around the world giving conferences.

One session of SCIO therapy costs between 400 and 1000 pesos, and therapists claim that between 10 and 15 sessions are needed for a full recovery. As a necessary prerequisite, patients have to stop taking any medication before undergoing SCIO therapy. The rationale for this is that drugs, being substances foreign to the body, poison it and stop the healing process.

The scientific community and the health professionals have strongly criticised quantum medicine on the grounds that it is not supported by actual scientific principles. They claim that this equipment only measures skin's electric currents, which are not related with the health of the person. Scientists argue that the placebo effect—in which the person believes a treatment will cure her/him—could be responsible for people feeling better when treated. The scientific community has said that relying on this therapy instead of going to the doctor can delay the diagnosis of serious diseases or, alternatively, a diagnosis produced by the device can alarm patients and make them spend high sums of money on unnecessary clinical tests.

The Food and Drug Administration (FDA), an autonomous governmental agency tasked with investigating and evaluating the effectiveness of drugs and therapies in the United States, denies the effectiveness of any of these kinds of therapies, and has even prohibited the importation and use of the device in the United States. Medical and scientific journals haven't published any research papers about this therapy.

Dr Nelson claims that all these criticisms and blockades are due to the fact that doctors fear losing their jobs and because there's a conspiracy headed by pharmaceutical companies whose aim to promote the use of the (usually expensive) drugs they produce—scientists as well as doctors lend support to these companies. Dr Nelson, nevertheless, advocates his system, one that offers more than 200 different therapies capable of diagnosing and curing almost all known diseases.

1. Would you recommend this therapy to your relative?

Yes	No	I don't know

2. Why?
3. What do you think about the mechanism of action of this therapy?
4. What do you think about the arguments of doctors and scientists?
5. Do you think that doctors, scientists, and the FDA are right when they criticise the SCIO therapy? Why?
6. What do you think about patients stopping any medication before receiving the therapy? Why?
7. What do you think about Dr. Nelson's opinion that scientists' criticisms to his therapy are due to doctors' support of pharmaceutical companies? Why?

Aids denialists

Maria is 25 years old. Three years ago she found out she was HIV-positive. She then decided to find out more about this virus and the disease it causes, AIDS. That's how she met the people at Asociación Monarcas Mexico. This association gathers people that claim that HIV is not the cause of AIDS, that it is curable, preventable, non-contagious, and eradicable.

The consensus of the great majority of scientists rejects this view, and argues that the role of HIV as the cause of AIDS has been proven beyond doubt thanks to a variety of experimental and clinical evidence. Scientists claim that they have observed the virus by using electronic microscopes, that they are able to detect its genetic material, the proteins in its surface, and the antibodies against it produced by infected patients.

However, the followers of Monarcas Mexico and other, similar organisations around the world believe that the evidence is inconclusive. They say that what is actually seen in microscope photographs is not the virus, that the tests for detecting patients' antibodies aren't specific for the virus, and that it hasn't been proven that the genetic material found in the blood of infected patients belongs to HIV, but rather is an altogether natural component of people's bodies.

Maria decided to join Monarcas Mexico and follow the therapies suggested by them, consisting of eating a healthy diet—so as to detoxify the body—as well as avoiding oxidising agents and stressful situations since, it is believed by the groups members, these are the true causes of AIDS. Maria hasn't taken any anti-retroviral medication because, according to the members or Monarcas Mexico, drugs contribute to the disease.

A week ago, Maria found out that she was pregnant. Her gynaecologist advised her that, in order to avoid infecting the baby, she must take anti-retroviral medication and that, once the baby is born, she must not breast feed it so as to reduce even more the risk of infection. However, in the association's leaflets, Monarcas Mexico recommends that pregnant women should not take anti-retroviral medication since it can prove dangerous both for the mother and the foetus. Likewise, they claim that it is cruel to deprive the newborn of the best kind of food, that is, mother's milk.

1. Do you think Maria—after finding out she was HIV positive—should have followed the association's recommendations?

Yes	No	I don't know

2. Why?
3. Do you think Maria should have followed the association's recommendations when she found out she was pregnant?

Yes	No	I don't know

4. Why?
5. What would you think if Maria decided not to take the medications recommended by her doctor?
6. What do you think about the scientists' stance?
7. What do you think about the association's claim about the scientific evidence not being conclusive?
8. What do you think about the association's treatment for HIV?

Mobile phones

In the year 2008 there were over 3 billion mobile phone users in the world. The increased use of these devices has become a cause for concern for some people.

Mobile phones transmit microwaves, which some people believe can be harmful. For some time now, a number of enquiries have been carried out to determine the actual effects of mobile phones on health.

Some *in vitro* experiments, that is, carried on cell cultures and not on animals or humans, have concluded that microwaves do alter the natural processes involved in cell death. This could mean that full-bodied organisms might develop cancer. However, scientists haven't been able to find these alterations in animals or people.

The European Union commissioned a study to scientists from 12 countries: they were all to perform identical experiments, in their home countries, aimed at assessing the health risk posed by the use of mobile phones. So far, the results are inconclusive because those studies that confirmed the harmful effect associated with mobile phones have proven impossible to replicate.

Studies that surveyed mobile phone users diagnosed with brain tumours and then compared their habits with those of users without brain tumours haven't found any differences in the habits of both groups.

Given the lack of information, the preliminary results are still controversial. The World Health Organisation (WHO), in accordance with the scientific and medical information available so far, claims that it's highly unlikely that mobile phones cause harmful effects, such as headaches, dizziness or tumours. However, WHO emphasises that, given the fact that the effects of radiation are not immediate, long-term studies need to be conducted. Likewise, almost all the research conducted so far has focused on individuals over 18 years of age, leaving the effects of mobile phones on children still to be determined.

Some countries, like the United Kingdom, have issued guidelines to help the citizenry reduce their exposure to mobile phones, especially children. Some of the guidelines recommend using landlines for long conversations and hands-free devices to keep the phone away from the body.

1. Do you think that Mobile phones can be harmful? | Yes | No | I don't know |
2. Why?
3. Do you think that the scientific evidence available so far is trustworthy? Why?
4. Why do you think that scientists haven't any conclusive results so far?
5. What do you think about issuing recommendations even when there is no conclusive evidence?
6. Would you follow these recommendations? Why?

Modified humans

In the United Kingdom, a group of scientists is trying to engineer human embryos containing the genetic information of three different individuals. With this, they hope to prevent hereditary diseases in children caused by faulty mitochondria. Mitochondria produce the energy that cells use. Mitochondrial diseases affect at least 1 in 8000 people and, currently, there is no effective treatment available.

People inherit mitochondria from their mothers. According to the pioneering technique being developed in the UK, a woman with faulty mitochondria that wishes to have children could have the mitochondria in her eggs partially replaced with healthy mitochondria taken from a donor and thus be sure of her children's health. The technology is controversial because mitochondria have their own genetic material, that is DNA, which means babies born in this way would have genes from two different women (besides the genes of the father).

People that advocate these experiments point out that mitochondria have only 37 of the approximately 20,000 human genes, and argue that replacing them is like replacing a battery. However, new data keeps accumulating that suggests that mitochondrial genes are more important than previously thought: they may be involved in athletic prowess, health, aging, fertility, and even, maybe, intelligence.

So far, there is no evidence that implies that the children born with the mitochondria of two women will suffer an illness, but there is no warranty that they will be healthy either. Some scientists argue that, even if children conceived with the aid of this technology are born healthy, any mitochondrial disease could reappear in later generations, since the mother's faulty mitochondria would be present inside the ova of any and all daughters. They also think that incompatibilities between mitochondria could arise, which could result in severe diseases and even miscarriages.

However, other scientists believe that this technology is highly promising and it would be "criminal" to prohibit it. Up until now, mothers that find out that their mitochondria are faulty face a terrible dilemma when they have to decide if they want to have children.

1. Do you agree with the genetic modification of embryos in order to prevent an illness?

Yes	No	I don't know

2. Why?
3. Who should decide if the embryos can be genetically modified? Why?
4. Why do you think scientists disagree about using this technique?
5. What would you consider in order to decide using this alternative to have children?

Cloned cattle

Cloned cattle are produced by extracting the nucleus of an unfertilised egg and replacing it with another nucleus extracted from the cell of a full-grown animal. Afterwards, the modified egg is subjected to an electrical pulse and, if the procedure is successful, the developing embryo is implanted in a surrogate mother. The newborn is thus identical to the full-grown animal from which the nucleus was taken. The most famous example of these procedures has been Dolly the sheep.

In January of 2008, the governments of Europe and the United States gave their approval to the sale of meat and milk from cloned animals or animals bred from them. Since then, an intense debate about the use of these products in the diet has raged on.

The FDA (the United States federal agency tasked with regulating foodstuffs and drugs) published evidence from several biotechnology researchers in a report. Among the most important conclusions of the report was that milk and meat from cloned cattle (cows, pigs, and goats) and animals bred from them are just as safe as foodstuffs obtained from non-cloned animals.

The potential benefits of cloning for breeders are huge, since cloning the best animals leads to high-quality foodstuffs. For the moment, the cost of cloning the best specimens is too high, of around 200,000 pesos, compared with the 30,000 of a conventional cow. In the future, the prices of cloned cattle are expected to go down as the technology involved in cloning improves. Presently, cloned animals are only used as studs with which to produce cattle, from which high quality meat and milk can be obtained. In the future, the properties of the meat and milk of these kinds of animals will be improved so as to reduce their cholesterol levels or increase the amounts of antioxidants and fatty acids beneficial for consumers' health.

On the other hand, consumer groups claim that the safety of meat and milk from cloned animals hasn't been determined. They argue that, to date, there are few published studies in peer-reviewed scientific journals devoted to the topic. Worse, the majority of published studies have been sponsored by biotechnology companies with a vested interest in getting favourable results. Consumers claim that there are differences of chemical composition of nutrients in foodstuff from cloned animals compared with non-cloned ones. The FDA, however, denies that these differences could be due to the cloning process and asserts that all nutrients are completely normal and suitable for human consumption.

The main criticism against eating foodstuffs from cloned animals comes from consumer groups that claim that cloned animals have more bouts of bad health compared with conventional animals. The FDA concedes that these animals do suffer from bad health, but emphasises that if these animals can reach maturity—the time when they are used to produce meat and milk—that is because they are as healthy as conventional animals.

1. Would you eat or drink meat or milk from cloned cattle?

Yes	No	I don't know

2. Why?
3. What do you think about the studies published by scientists about the safety of these foodstuffs? Why?
4. Do you think that the breeders have the right to sell these products? Why?
5. What do you think about the FDA's stance?
6. What do you think about the breeders' stance?
7. What do you think about consumer groups' stance?

Self-medication

José had had a great time at the party. The only problem was that the next morning he just couldn't talk; his throat was throbbing, which he ascribed to the singing and yelling of the past night. That morning he had several classes to attend, so he got up and went to the university.

As the day went by, José began to feel chills, muscle pain, headaches, and his throat didn't feel better. His friends suggested a few home remedies, but none worked. At home, he found some capsules of antibiotic left over from when her sister had a cough. He decided to take them. He remembered that her sister had taken them two times a day for seven days. The remaining capsules were not enough to complete a treatment. Luckily, at the fourth day he already felt a lot better, so he decided not to buy more capsules.

José, like 75% of all Mexicans, self-medicates, that is, he decides what drugs to take without consulting a doctor first. Some drugs, so-called over-the-counter medications, such as aspirins, paracetamol, Alka-Seltzer, and some others, can be bought and sold without a prescription. However, some drugs carry the warning "not to be sold without prescription" and "Dosage: as prescribed by the doctor". Unfortunately, in Mexico these drugs are easily obtained in drugstores without a doctor's prescription.

Scientists and doctors agree that self-medication can have serious consequences for one's health, and not just individually but also for the community as a whole. In 2007, nearly 45,000 people died as a result of self-medication.

The indiscriminate use of antibiotics has given rise to resistant bacteria, more difficult to fight than previous ones. Self-medication can mask the symptoms of a disease, making it difficult to diagnose, cause allergies or poisonings, or worsen other illnesses.

1. Do you think José should have taken the antibiotic?

Yes	No	I don't know

2. Why?
3. Have you self-medicated?
4. Why do you think someone self-medicates?
5. Do you think these are valid reasons? Why?
6. Do you think that there is enough evidence to prove that self-medication is harmful?
7. What do you think the evidence consists of?
8. Do you think the evidence is trustworthy? Why?
9. If you decided to self-medicate, would your attitude to self-medication change now that you know the consequences? Why?

Smoking

Many researchers claim that smoking is responsible for a large proportion of cancers and for approximately 30% of all cancer-related deaths. Smoking is a cause of lung, mouth, larynx, oesophagus, bladder, kidney, and pancreatic cancer. Researchers claim that smoking can cause up to 25 to 30% of cardiac disease. In Mexico, around 165 persons die on a daily basis due to smoking-related complications.

The risk of cancer is bigger in people that smoke heavily and in those that start smoking at a young age. Many people start smoking while adolescents and it has been shown that once one starts smoking, it's hard to quit.

Recently, the nicotine in cigarettes has been shown to be a highly addictive drug, exceeding even the addictiveness of opium and heroin. Furthermore, some reports have been published that indicate that some tobacco companies use a variety of methods to increase the quantity and potency of the nicotine in cigarettes.

The exposure to cigarette smoke can also be a cause of cancer in non-smokers (passive smokers). Some scientists warn that the risk of developing cancer in passive smokers increases up to 50%. It is estimated that thousands of people die each year due to passive exposure to cigarette smoke.

Due to the risks associated with smoking, on 3 April 2008 the Anti-Tobacco law was implemented. The law prohibits smoking in closed spaces like offices, restaurants, pubs, and schools, among others. Whoever smokes in these places can be punished with 36 hours in jail and the owners or administrators of the place can be fined with up to 130 thousand pesos.

1. Do you smoke? ☐ Yes ☐ No
2. Why did you decide to smoke/not to smoke?
3. Do you think people are aware that cigarettes are harmful? Why?
4. Do you think there is enough evidence to prove that tobacco is harmful?
5. What do you think the evidence consists of?
6. Do you think the evidence is trustworthy? Why?
7. Do you agree with the Anti-Tobacco Law? Why?
8. Should smoking be banned? Why?

Diet and diabetes

Patients with diabetes suffer from high levels of blood sugar (particularly glucose). Although incurable, this disease can be managed and, in some cases, even prevented. The consequences of the disease are severe, ranging from skin infections to problems of the circulatory system, kidneys, and eyes. There are two kinds of diabetes, the most common of which is type-2 diabetes in adults, although increasingly prevalent in children and teens.

Scientists and doctors have discovered that overweight people run a higher risk of developing type-2 diabetes. Body fat around the abdomen is the most harmful in that it favours the onset of diabetes. That's why doctors measure the diameter of the waist in order to assess the risks to health posed by obesity, among which diabetes is one. A balanced diet, rich in fibre and low in fats helps prevent or manage type-2 diabetes.

Many studies show that people that exercise regularly have less risk of developing diabetes. Even people with more than one risk factor for diabetes, whether inherited or related to obesity, can diminish their propensity to develop diabetes through physical activity. Scientists claim that the prophylactic effect of exercise lies in the fact that it forces the body to consume fats and sugars more efficiently. Some studies have shown that more than 25% of cases of type-2 diabetes are the result of sedentary lifestyles.

1. Do you lead a healthy life-style? ☐ Yes ☐ No
2. Before reading the text, did you know that a healthy diet and exercise help to prevent diabetes?
3. Do you think that there is enough evidence about the role of a healthy diet and exercise in the prevention of diabetes?
4. What do you think the evidence consists of?
5. Do you think the evidence is trustworthy? Why?
6. What makes you decide to exercise or not to exercise?
7. Why do you have a healthy diet or why don't you?
8. What would it take for you to change your life-style for a healthier one?

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