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REFLECTING ON SCIENTISTS' ACTIVITY BASED ON SCIENCE FICTION STORIES WRITTEN BY SECONDARY STUDENTS

Abstract

In this article the authors resort to a qualitative analysis of the plot of science fiction stories about a group of scientists, written by two 11th grade Earth and Life Science students (aged 17), and to semi-structured interviews, with the double purpose of: a) diagnosing their conceptions of the nature of science, namely as regards scientists' activity; and b) discussing the potentialities of this methodology in terms of research and education in science.

The adopted methodology proved particularly effective in diagnosing the students' conceptions of scientists' characteristics, scientific activity and science-technology-society interactions. The limited content of certain conceptions and a certain lack of knowledge on the part of the students concerning the processes and the epistemology of science highlight the need to pay explicit attention in science classes to the nature of scientific activity. Some of the ideas brought up by the students clearly show the influence of stereotypes and catastrophic scenarios depicted in films, television programs and books, revealing media's limitations when divulging scientific and technological themes to the general public and stressing the need for the school to promote a critical debate about science and technology images conveyed by the media.

Key Words

Science Education; Science Fiction Stories; Nature of Science; Learning Activities; Media.

Introduction

Despite the controversies between educators, historians and philosophers of science as regards its meaning and its pedagogy, the nature of science is a crucial aspect of science curricula in many countries (Jenkins, 1996). Currently, learning about the nature of science and its relation to society and to culture is as prized as learning scientific contents and procedures (McComas, 2000). Usually the term *nature of science* refers to the epistemology of science, that is, to science as a form of knowledge or to the values and beliefs underlying the development of scientific knowledge (Abd-El-Khalick, Bell and Lederman, 1998; Lederman and Zeidler, 1987). This expression is used in science education as a description of scientific activity. The nature of science combines aspects of the history, sociology and philosophy of science with research from the cognitive sciences (namely psychology), in an attempt to gather a rich description of what science is, how it works, how scientists work as a social group and how society itself directs and reacts to scientific endeavor all in one (McComas, Clough and Almazroa, 2000).

It is up to the teachers to establish a bridge between the culture of scientific community and the rest of society, by initiating students in certain aspects of scientific culture (Sorsby, 2000). Teaching about the nature of science (especially about the social, institutional and political frames within which science works) is believed to encourage students to appreciate science

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as a human endeavor with a history, adventures, personalities, dramas, fights, controversies, creativity, rules and ethical principles (Driver, Leach, Millar, and Scott, 1996).

Theoretical Background

One of the main goals of science education is helping students to develop an understanding of the nature and methods of science and an awareness of the complex interactions among science, technology and society (Hodson, 1998a). The development of a more real, multifaceted image of science (that takes into account the critical reflections of philosophy, history and sociology) may contribute to improve the relation between science and society, thus representing the best antidote against contemporary views tending towards irrationality and catastrophe. In scientifically and technologically advanced societies, understanding the scientific enterprise (namely scientists' activity) and its interactions with technology and society is essential for citizenship and democracy, allowing common citizens to take part in decisions concerning socioscientific issues (Millar and Osborne, 1998).

However, few individuals have a basic understanding of how scientific activity works (McComas, Clough and Almazroa, 2000; Miller, 1991). Both school and non-formal education agents (specifically, the media) may be held responsible for this situation. Several authors believe that school contributes explicitly and implicitly to the construction of limited conceptions of the nature of science (Duschl, 2000; Hodson, 1998b; Monk and Dillon, 2000). Various studies have shown that many teachers: a) possess distorted conceptions about the scientific enterprise and scientists (Lederman, 1992; McComas, 2000); and b)

Deleted: One of science education's main objectives should consist of acquainting students with the characteristics of scientific work, helping them understand its courses and numerous aspects, placing them in a position of active citizens with the capacity to decide in pluridisciplinary situations, where science is one of several voices of society (Hodson, 1998a). The development of a

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do not include issues concerning the nature of science in their planning (Abd-El-Khalick, Bell and Lederman, 1998; King, 1991; Lakin and Wellington, 1994; Authors, 2004a). During their beginning and in-service education, teachers rarely have the opportunity to reflect on aspects related to the nature of science and therefore tend to undervalue them in their teaching practice (Lakin and Wellington, 1994; McComas, Clough and Almazroa, 2000; Mellado, 1997). Both teachers and science textbooks are strongly associated with a tradition of 'delivery' of facts and final products of science and, generally speaking, they neglect the way this knowledge is constructed (Gallagher, 1991). For most science students, a description of the nature of science is relegated to a short comment about a few paragraphs at the beginning of the textbook (Bentley and Garrison, 1991). School science is often presented as a body of perfectly established, non-controversial knowledge, built upon an algorithmic process ("the scientific method") that is objective, value-exempt and that leads to indisputable truths. However, the socioscientific issues society has faced reveal a real science that is totally different, marked by conflicts resulting from different opinions, values, personal conveniences, social and economic group pressures, and so on.

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At the same time, non-formal agents of scientific education, namely the media, have not exactly set out to clarify the population about the way scientific and technological activity works. This situation is quite serious because keeping the population up-to-date in scientific matters largely depends on the information conveyed by the media (Lewenstein, 2001). Often television and newspapers deliver a distorted image of science and stereotypical ideas about scientists and their activity, producing a significant impact on the public's

conceptions and trust regarding scientific and technological endeavors (Nelkin, 1995; Authors, 2004b). Scientific research is repeatedly presented as an esoteric, mysterious and extremely complex activity, whose understanding and practice are only within reach of a handful of insightful experts who spend their lives completely isolated and absorbed by their work. Whether they are covering the Nobel awards, scientific frauds or controversial theories, the media describe scientists as superior beings competing over prizes or prestige; sometimes the intensity of this competition is such that it leads to fraudulent or ethically arguable practices. This kind of news ignores the process of scientific knowledge production and conveys a feeling of awe towards science that helps perpetuate the distance between citizens and science (Nelkin, 1995).

Problem and Methodology

This paper deals with the analysis of two science fiction stories about the work of a group of scientists, written by two 11th grade students (aged 17), with the double objective of: a) tracing their conceptions about the nature of science, namely as regards scientists' activity; and b) discussing the potentialities of this methodology in terms of research and education in science. These two stories were written as part of a larger, mainly qualitative project, based on case studies, aimed at studying the impact of recent controversial socioscientific issues – made public by the media – on the pedagogical practice of a Portuguese group of Earth and Life Science teachers and on the conceptions these teachers and their students have about science and technology (Author 1, 2004; Authors, 2004 a, b). This study implied gathering different information through semi-structured interviews, observation of class sequences and the

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analysis of documents produced by the participants (class planning and materials, in the case of the teachers, science fiction stories in the case of the students). For this article, the data referring to two of the participants of the above-mentioned larger study were randomly chosen from a well-written and well-structured set of stories. The two stories were chosen as examples – one containing positive ideas about scientists; the other one presenting some negative/pessimistic ideas about scientists – to illustrate the potentialities of the chosen methodology.

Each student was asked to write a science fiction story involving a group of scientists working on a particular situation of her/his choice. The fictional element was chosen because of the interest it arouses in students (Freudenrich, 2000). The science fiction story was assigned as an individual homework task. Students were told to refer explicitly to the work of a group of scientists so as to guarantee information gathering about relations within the scientific community. These stories represented a way of accessing subjects' possible conceptions about the scientific enterprise. The plots of the science fiction stories that were created are believed to reflect a combination of: a) students' ideas about science; b) images deriving from the media and science fiction films and books; and c) the set of elements that students identify as part of a good science fiction story. Therefore, the analysis of the plots of such stories did not provide a clear or complete portrait of the students' conceptions of the scientific activity and the characteristics of scientists; rather, it merely offers evidence that may then be clarified, broadened and discussed through interview.

After the researchers had read the stories a first time, the participants were invited for a semi-structured interview at the school to clarify, deepen and discuss in detail the ideas incorporated in the plots of their stories. The interview was also used to broaden the scope of students' expressed ideas about science, focusing on particular aspects of the nature of science that were not covered by the story plot. A core set of questions guided the discussion of the story plot (see appendix A). However, several other questions were used to pursue and explore some interesting ideas expressed by students. The interviews were audiotaped and transcribed for analysis.

The science fiction stories and full transcriptions of the interviews underwent a process of content analysis, using a model of analytical induction (Bogdan and Biklen, 1992), followed by a process of triangulation. By re-reading the stories and analyzing them more deeply, certain categories emerged – e.g. images of science, interactions between science and society, characteristics of scientists and scientists' motivations – as well as even more specific subcategories corresponding to specific aspects. This process was accompanied by each story's excerpt classification, according to the defined categories. Initially, all data were analyzed separately by each researcher. Following this, the results of the analysis were discussed not only by the two researchers, but also by two other colleagues of the same research centre. Discrepancies were discussed and resolved by agreement between all four researchers.

Results: The Cases of Ana and Miguel

The following case studies were constructed through the analysis and triangulation of information gathered from the science fiction story and the semi-structured interview (Student Interview – SI). Each case presents a brief description of the student, the full version of the science fiction story he/she wrote and some evidences of his/her conceptions about the nature of science and technology, obtained through the joint analysis of the story's plot and the interview contents. The full version of the science fiction story is presented to illustrate the richness of each narrative different aspects and the quantity and quality of information gathered through this methodology. The stories constitute linguistic units which establish meaning, enabling the reader to feel with others or see through others' eyes (Egan, 1988).

Ana's Case: "No-one can do research alone. You always have to have other data already discovered by other people"

Ana finished the 11th grade with an 18/20 average; in Earth and Life Science she got 19/20. Over the last few years she has focused on her dream of becoming a doctor, a common occupation in her family which she claims to "admire" and will allow her to "help others". In her free time she likes to read and paint. She turned 17 while this investigation took place.

When she wrote her science fiction story she thought of addressing the rather present-day topic of cloning. But, predicting a substantial number of assignments on this topic in her class, she chose another topic she thought was equally important because of its huge social impact: cancer. In order to find out more about this theme, she turned to one of her uncles, a doctor, with whom

she talked before writing the story. The plot portrays Ana's dream of working professionally in medicine in something that would allow her to contribute to reduce human suffering.

The Science Fiction Story

The Cure for Cancer

Sometimes we think very little of ourselves and that our existence won't change the world, but that's not quite right…

Chapter 1 –

First of all, my name is Sofia Sousa, I'm a doctor, but during my career I decided to follow the field of research. For several years I studied all types of cancer, came into contact with patients and talked to colleagues who deal with cancer everyday… I have always aimed in life to discover the cure for this disease, this horrible disease that is fatal in some cases and that is increasingly affecting our society.

It may seem a bit odd to direct my life towards discovering the cure for cancer, but I shall explain the reason for my choice. When I was 13 my father died of cancer. It was very difficult for me to see him getting worse by the day and to see that the treatments he underwent sometimes made him worse, and other times gave him the illusion that he was better (and that he could beat the disease) but he didn't manage to pull through. From that day onward I swore I would do my best so that no-one would have to go through what I had to endure, suffer what I had suffered. That's why I have this big desire to find a cure for cancer. But it hasn't

been easy. Currently, the fight against cancer involves various types of medication and treatments administered simultaneously to try to destroy the cancerous cell. This cell is quite different from normal cells because unlike these it is immortal: while normal cells keep dying and are replaced by others, cancerous cells never die and keep dividing. Sometimes these cells become resistant to treatments, creating defenses against them and making it impossible to fight them.

Despite all these difficulties I still haven't given up looking for a cure for this disease. I have worked for years, done research and the ideal solution to the cure for cancer implies medication that goes directly to the chromosome and changes cell genes so they stop being cancerous. But this solution isn't as easy as it seems; on the contrary, it's quite complex, because besides needing medication that works quickly and doesn't give time for the cell to create defenses to fight it, it also involves critical genetic issues. My colleagues and I have made several attempts but we still haven't found the perfect substance. But I keep hoping that eventually we will...

Chapter 2 –

Some time ago I spoke a little about my work and my life. Well, over the last months I've worked quite a lot, I spent sleepless nights in the laboratory carrying out tests with guinea-pigs, to see if they would have any success, but unfortunately they all failed. However, I haven't give up, I never will, I hope to find the perfect substance that will fulfill my aim in life. Of course I was never alone in this investigation of mine, I had the

help of several colleagues of different nationalities who, like me, devoted their body and soul to this work. We exchanged ideas and findings in this field; some had done a lot of progress and achieved breakthroughs in this field, providing me with new knowledge. One of the most important colleagues is an Englishman, Dr. John Darcy, with whom I continue to work. His story isn't as dramatic as mine, there were no cancer-related deaths in his family, but his effort and desire to stop this disease are as strong as mine. We talked quite a lot and he told me that he had been working with cancer patients for several years and cured some of them, but unfortunately many of them had passed away. The families' suffering shocked him, as did the fact that he couldn't stop that suffering, and he decided, like I did, to investigate a possible cure and thus turned to research. Despite not having lost any loved one to cancer, he is totally dedicated to his work, just like me. He has made important findings in this field, and I think that with his help we are going to reach our goal: the cure for cancer.

Chapter 3 –

I think that today, at long last, I feel fulfilled. After having worked for two seemingly endless years with my colleagues on a substance to cure cancer, we have finally succeeded. I don't regret a single day I spent on this research because it will have been worth every minute seeing that from now on no-one will die of cancer and no more families will lose a member to it. We are not solely responsible for having found the cure, so are our colleagues working in genetics, whose findings were essential for

our work. This substance worked on the guinea-pigs, but we weren't sure it would actually work until we tested it on human beings. Luckily it worked and we were ecstatic when we discovered that cancer would no longer be a problem for people because we'd managed to beat it. This substance causes no physical pain, and when it is taken it changes the cancerous cells genetically so that they stop being cancerous and become normal. It acts quickly and the cancerous cells can't defend themselves.

At this moment we're famous but that's irrelevant to me, because my goal was simply to find a cure for cancer. John and I aren't going to give up our profession and we're going to keep doing research in other areas. Right now I can't describe what I'm feeling and I think my colleagues feel very much the same way, something impossible to explain but which makes you feel good. I know that there are still other serious diseases that are incurable, for now, but cancer was among those that caused most deaths in our society. The mere fact that it can be cured will already prevent many families from feeling the way I felt. This is precisely what gave me the strength to devote myself to my work, the simple fact that I'm sure that I contributed towards sparing several families the endless sadness that I felt for having lost to cancer someone very dear to me.

Conceptions about Scientific and Technological Knowledge

In her science fiction story, Ana describes scientists as special people who seek solutions to societal problems in an altruistic, determined, persistent and committed manner. This idea is fully confirmed during the interview: she

claims this commitment, enacted in years of hard work and sleepless nights, is essentially motivated by the desire to contribute to the reduction of human helplessness and suffering in face of serious clinical conditions, often lived first-hand by the scientists themselves. Other motivations, such as fame and the scientific community's recognition, come in second place. Ana considers the scientific enterprise a personal and collective crusade carried out by some individuals whose nature is deeply humane, determined and persistent. Several investigations have shown that these ideas about scientists' characteristics and motivations are shared by many students from different countries and levels of schooling (Aikenhead, 1987; Driver, Leach, Millar and Scott, 1996). Often the media themselves present this mythical vision of the scientist as a superior, altruistic being, free of any selfish motivation whatsoever (Nelkin, 1995).

In Ana's opinion, revealed in her story and confirmed during the interview, scientific activity is a collective enterprise undertaken by multidisciplinary international teams of scientists, based on pre-existing theories and activities, both laboratorial and theoretical, which allows knowledge to move on through "discoveries". This opinion is contrary to two common conceptions among students and the population at large: (1) the idea of science as a solitary enterprise built upon the individual discoveries of great scientists; and (2) the notion that science is constructed exclusively through experimentation, ignoring the use of other methodologies (McComas, 2000). Ana thinks that collaboration among specialists from different fields and the recourse to different methods enhance the efficiency of science to solve today's problems and to produce new knowledge. She believes that scientific theories are "universally accepted" after they are "established as being true" by the "scientist community" through a

process similar to “a vote”: for the theory to be considered “true”, “everyone has to reach an agreement… which is difficult” (SI). From her statements it is possible to identify the conceptions: a) of theory as a “universally accepted truth”; and b) of the importance of the scientific community’s role in discussing and eventually recognizing a theory. The interview allowed discussing these particular aspects of the nature of science not covered by the story plot. Throughout her interview Ana was incapable of defining the concept of theory, and simply mentioned a few examples addressed in classes (for instance, the Theory of Evolution). She also revealed some difficulty in reconciling this status of “universally accepted truth” with the idea, sometimes referred to by her teachers (and which she acknowledges as being correct), that scientific theories may suffer changes or be abandoned.

According to Ana’s story and interview, the future is promising as regards scientific and technological progress. However, she feels that the mission of scientists is endless, and warns about the possibility of using science in a positive or negative way: “We’re going to progress quite a lot and I think that the cures for several diseases will be found, but then others will emerge and it’s going to be like that forever. (...) And the advance of science can hold both advantaged and disadvantages.” (SI). In her opinion, the future fully depends on the ethical and moral dimension of scientists and of citizens in general. It is up to all of them to decide how to use scientific knowledge.

Miguel's Case: "I believe a lot of research is done in secret... Then accidents happen and people don't know"

Miguel was 17 years old at the time this investigation took place. He finished the 11th grade with a 15,5 average and got 17/20 in the subject Earth and Life Science. In his free time he skates and plays guitar in a band. He has always wanted to get a degree in engineering. At first, influenced by his father's professional activity, he wanted to do Mechanical Engineering, but the lack of professional options in this field in the future and his growing interest in environmental issues motivated him to go for Environmental Engineering.

His attraction to engineering in general, and to the radiation theme in particular (radiation emitted by cellular phones, nuclear radiation, solar radiation and so on), influenced his choice of subject for his science fiction story. Miguel claims that the plot of his story reveals many of his ideas and concerns, namely as regards the manner in which he thinks scientific activity is conducted. Therefore, his plot "is not just a good science fiction story that is impossible to happen one day" (SI).

The Science Fiction Story

The Conspiracy

Chapter I – Introduction

Dr. Nunes slowly went down the stairs towards the hallway. While he waited at the door for the taxi he'd called to take him to the airport, he looked around. What a sad sight! It was sad to see how people talked about the problems of the world so naively full of certainties. Neighbors

and people he didn't know would go past him in conversation, attributing great importance to so-called "crises" that hardly affected society. He felt quite depressed with the thought that he was witnessing the greatest of all tyrannies – the concealment of facts.

At that moment, the world completely ignored the dangers it would be exposed to in a matter of hours. Bribed or threatened to keep quiet, or totally ignorant regarding the issues they spoke of, journalists would write reports whereby they would get people to think that new technologies applied to microwave ovens and cellular phones do not have such devastating effects. They would talk about those hideous radioactive waste deposits as if they were very safe and reliable, without mentioning the chance that future generations might suffer because of them. They only warned people to be careful about catching too much sun (and other natural sources of radioactivity). As for atomic experiments, no-one discussed them because they were thought to be over.

Chapter II – The trip

Three hours after arriving at the airport, he got on a plane to Seattle (USA) with his prestigious colleague Dr. Álvaro Santos. The rest of his team was to fly a plane that took off two hours later. Dr. Nunes' physics research team had been called to participate in a top-secret project about nuclear testing in space. Only a few influential government members of the countries involved knew about this experiment. From the start, the position of Dr. Nunes and of all his colleagues had been against these experiments; and, for a year, practically with no holidays, they carried out

an investigation in order to demonstrate the possible devastating consequences on our planet. With their work they drew the conclusion that, considering the distance the tests were supposed to be carried out, there was a 47% chance that radiation would cross the ozone layer and its effects would be catastrophic. It would be as if half the bombs had exploded on earth. It was definitely the greatest risk humankind would have to face. But these figures were not enough to stop the ambition and madness of the other teams involved in this project's group.

In Seattle they were met by Dr. Smith, a young and ambitious American scientist. At once Dr. Smith told them the surprising news that the rest of the team had stayed behind in Lisbon airport and that their flight had been cancelled due to a suspicion that terrorists were going to board that plane. Being superstitious, Dr. Santos commented in Portuguese with Dr. Nunes: "Today is Friday, the thirteenth, and things are already going badly!"

Chapter III – The arrival

Around 18.13, they reached the hotel where they were to stay with the other five teams. They also learned that the rest of their team would only arrive the following day, which made all of them give up on the trip. Over dinner, they were warned to limit their conversations so that no-one around them would suspect a thing.

Chapter IV – Launching the bombs

Finally the big moment was arriving. Dr. Nunes looked at his truck as a "ticket to hell". The fact was that the whole time spent in the truck and in the field was truly hell. After the explosion, Dr. Santos broke the silence with a tactless remark: "This sight is at once beautiful and horrible!".

Chapter V – The lie

The next day, the whole world was talking about the explosions viewed that dawn. Governments agreed in a meeting with G8 to pay astronomers around the world to say they had suspected that several collisions with asteroids would occur, but that they did not have enough evidence to prove this would actually happen.

Chapter VI – The consequences

A year and a half went by. Throughout the whole world new cases of cancer and leukemia were popping up like mushrooms. High levels of radiation were said to have been detected, but no-one knew its source. Some newspapers said that probably it had to do with the destruction of the ozone layer, others thought that all electrical appliances emitted radiation. Only a few weekly papers that addressed more scientific topics questioned the relation with the comets.

For all the research teams it was clear what was happening. So they decided to schedule a meeting with all those involved in the project and suggested that a conference be held to tell the world the truth, as everyone was entitled to know what was going on. Their studies suggested the hypothesis that late effects might cause an anomaly in the

reproductive organs, which meant that the majority of humankind would be sterile for about 20 years. Dr. Nunes was shocked when he left the meeting. They actually were cruel enough to say that "this catastrophe will be an asset to overpopulated countries", or they simply said, "What about the riots this would cause? And the civil wars?". He only saw fear in those faces. They weren't deciding what was best for humankind, they were simply thinking about what would be more convenient to each one, individually.

Chapter VII – The end and the continuation of human life

Five years later, in Portugal, only 9 children had been born, 6 of whom had died of cancer or leukemia.

Considering these events (and with a guilty conscience), a new meeting was held, to reconsider the conference. This time the governments refused the proposal. It was too late for that. Nothing could be done now, so the conference would just cause havoc. Dr. Nunes felt the weight of having accepted to take part in that project. He felt like a murderer regretting his action. The meeting ended with some moments of silence for the soul of Dr. Yanch, a Japanese scientist involved in the project, who had committed suicide after his wife died of leukemia.

Chapter VIII – The truth unfolded

The lives of the scientists who knew the truth became unbearable, for they couldn't tell their relatives the truth and sometimes had to watch them die, and feel they were to blame for their deaths.

However, though they shouldn't do it, both Dr. Beneditte, a Frenchman living in Chicago, and Dr. Frank Noggel, a member of the German group, could not resist and spilled the truth out to their relatives.

Several years had gone by and humankind was reduced to less than two thirds. The world was completely terrified by this catastrophe. After the death of Marie Beneditte (the wife of Dr. Beneditte) of pancreatic cancer, their son, François Beneditte, felt terribly angry and decided to reveal to the world all that had happened and to disclose the names of each person involved in bombs launching. It was total madness. Everyone showed their feelings in the most violent manners.

Chapter IX – Chaos

Some months after the day the world faced the truth, Dr. Nunes was shot to death by an angry citizen, as he left his house in Lisbon. The same happened to other scientists, like Dr. Beneditte. Dr. Beneditte's murder drove his son to madness and he was put in an asylum in the final year of his university course.

In many countries, with less organized or less powerful police forces, the chaos and revolution caused total anarchy. Society in general turned to several religious movements, in a desperate attempt to find salvation. The press lost all the credibility it had once enjoyed.

After two decades, the first babies were born. Most were deficient and looked grotesque, but contrary to predictions, almost no abortions were carried out, because couples were afraid they might not manage to have

any more children. The average life expectancy dropped drastically. Deserts had covered many African and Central American countries.

A few years after the world had stabilized its evolution in 2056, a school discipline was created, the aim of which was to moralize children to see if their generation would make the difference, so children would want to change the world, forget selfishness, greed, ambition. This discipline was created in most countries, but it was no good. Selfishness, greed, ambition, all these are born with man and die with man. They have become innate features and nothing can be done to change that.

Conceptions about Scientific and Technological Knowledge

In Miguel's entire story a strong sense of mistrust and impotence comes through regarding (1) scientific and technological options that are the sole responsibility of scientists or government entities and (2) the manipulation of the media by these lobbies. In his opinion, expressed during the interview, it is difficult for the population to intervene in processes it does not know of.

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Reflecting on the plot of his science fiction story, Miguel is emphatic about the existence of "a lot of scientific research that is done in secret by scientists driven by fame and profit" (SI). He believes that secrecy is often guaranteed by the State, so as to allow projects that are methodologically risky, and have controversial aims, to be carried out without the scrutiny of the population at large.

Another powerful element in Miguel's interview is his enormous concern with the on-going environmental degradation of Earth, caused by the

thoughtless and irresponsible use of technology. Many times he calls for more investment in the prevention and in the resolution of environmental problems, both of which he finds well below desirable standards.

Miguel speaks out against the myth of the seeming objectivity and neutrality of science, common among students of several ages and nationalities (McComas, 2000), when he feels that selfishness, greed and ambition are characteristics of human beings (subsequently of scientists) that render the execution of all sorts of scientific and technological projects unavoidable, regardless of their potential dangers. Both his science fiction story and his discourse during the interview reveal the belief that the execution of potentially catastrophic projects depends solely on the extremely dangerous combination of two factors: the lack of scruples and the power of decision and of implementation. They also indicate the acknowledgement of science as an enterprise which, despite being collective and international, is decisively influenced by the countries and scientists with greater technical, financial and decision-making power. The others, competency aside, are pushed to the minor role of totally impotent spectators.

Despite these concerns, Miguel acknowledges the important role science and technology have in improving the quality of life of the population. He believes scientists are “normal people” (some of them “superstitious”), with family, diverse intellectual, moral and ethical traits, who are devoted to scientific research; in other words, they seek “to achieve a better knowledge, summing everything up so as to find out more, (...) so we understand the things that surround us better and also to enable many things, such as the construction of machines to make life easier” (SI). This statement unveils an identification of

science with the production of technological artifacts, which corresponds to a common conception among students, in an era characterized by the growing subordination of scientific research to its technological applications (Aikenhead, 1987; Fleming, 1987; Ryan and Aikenhead, 1992).

Another interesting aspect of this science fiction story is its exclusive reference to male scientists (eight in all), which represents a common stereotype among many students (Chambers, 1983; Fort and Varney, 1989). This idea was confirmed by Miguel in the interview: "I think that the great majority of scientists are men" (SI). This idea is particularly interesting in Portugal (a country where women form the majority of university students and a very substantial and growing percentage of scientific investigators) and suggests a heavy influence of science fiction films and books (often marked by this stereotype).

The interview allowed discussing other aspects of the nature of science that were not particularly covered by his science fiction story. Through the interview, Miguel reveals quite a lot of difficulty in describing scientists' work, namely the methodologies they use. However, he considers that in general scientists' proposals are tested in laboratories or in the field, which shows an experimental-inductive conception according to which scientific activity is confined to an algorithmic process including (1) observation of phenomena, (2) elaboration of explanatory hypotheses and (3) their testing. Sometimes this idea is conveyed in natural science classes when scientific activity is described as a rigid sequence of phases sometimes called "the scientific method" and lab work is presented as a way of "proving" knowledge addressed in theoretical lectures. Miguel also believes that testing scientists' proposals by the international

scientific community is an essential condition for their acceptance as theories. In his opinion, a theory consists of a hypothesis, or explanatory idea, evaluated and recognized by the scientific community. However, according to Miguel, theories are temporary and can never become outright "truths" due to the ever present possibility of reformulation after the discovery of new data.

It is likely that this student's lack of knowledge regarding procedural and epistemological aspects of science accounts for much of his mistrust regarding scientific activity. We usually fear what we do not know. The situation is made worse by the media who are, as mentioned above, the population's main source of scientific information (Lewenstein, 2001). The fact that the media rarely portray scientists positively has a considerable effect on the public's trust in science and in technology (Haynes, 2003; Weingart, Muhl and Pansegrau, 2003).

Final Remarks

This study illustrates the potentialities of the joint use of science fiction stories, written by students, and interviews for identifying and discussing students' conceptions about scientists and the scientific enterprise. The science fiction stories written by students were a particularly interesting source of information, full of signs regarding students' conceptions and their likely origins. The discussion (during the interview) of several details and signs included in each story led to a rich diagnosis of its author's conceptions. The wealth of information was especially remarkable as regards the conceptions about scientists' characteristics (whether cognitive, socio-affective, moral or ethical), scientific activity (objectives; places where it takes place; methodologies and

tools used; relations among scientists) and the interactions between science, technology and society (the social impact of science and of technology; the control of research by society; relations between science and technology; the fear of possible undesirable side effects stemming from scientific and technological innovation, among other aspects). The interview was also interesting because it allowed broadening the discussion to other specific aspects of the nature of science not covered by the story plot (namely, the construction and validation of scientific knowledge, procedural aspects of science or students' conceptions on "hypothesis" and "theory").

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The students' satisfaction with the fact that they were asked to write a science fiction story was also remarkable. This would not have happened so easily if a questionnaire had been passed round, or if only an interview had taken place. Taking all this into account, the joint use of science fiction stories (about scientists' activity) and interviews seems to surface as a promising methodology for investigating students' conceptions about the scientific enterprise.

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Some of the ideas presented by the students clearly show the influence of stereotypes and catastrophic scenarios (the scientist as the hero and savior of society; the dangerous, ruthless scientist working on secret, controversial projects; and the scientist incapable of controlling the result of his work) depicted in films, television programs and books, denoting some limitations of the media in transmitting scientific and technological topics to a broad audience. Many of the programs shown on television (films, cartoons) have not promoted much of a discussion about scientific activity and focus mainly on the downsides

of technological innovations, thus conveying a negative image of scientists and of their work.

The media's impact on students' conceptions, as found in this study, stresses the need to create room for a critical debate, in the context of the classroom, of the images portrayed by the media with respect to science and technology. Analyzing and discussing pieces of news, films or science fiction stories written by students may prove quite useful in constructing a more real image of the scientific and technological enterprise and its interactions with the socio-cultural context.

The limited content of some conceptions and a certain lack of knowledge about science processes and epistemology, revealed by the students, show the need to pay special attention to the nature of scientific activity in the science class. In the same way that learning a language implies knowledge on form, grammar and vocabulary, scientific education requires knowledge about the great topics of science, some of its contents, its agents, its methods and its uses and abuses (Osborne, 2000). Therefore, the development of scientific literacy necessarily entails a less factual, fragmented science education – one that does not isolate science and technology from the socio-cultural contexts of their construction – where the production of contemporary science can be discussed critically in terms of its different procedural aspects and of the political, economic, social, environmental and ethical issues it arouses. Classroom discussion of the plots of science fiction stories written by students may prove a rather efficient catalyst for challenging wrong and/or stereotypical ideas about the scientific enterprise, and for learning about scientific processes and epistemology. This activity may represent an important element in a type of

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teaching that is not limited to facts, but rather includes the social aspects of science associated with topics that the students do consider up-to-date and relevant.

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Appendix A

Discussion of the Story Plot

1. Which reasons made you choose this plot for the science fiction story?
2. What is your personal opinion about the theme of your story?
3. Where did you gather the information you used in your story?
4. Do you believe that scientists are just like you described them in your story?
5. In your opinion, are there certain characteristics that distinguish scientists from the rest of the population? What does scientists' work consist of? What are their professional motivations?
6. What is your opinion about the future of science and technology?