Students' epistemological awareness concerning the distinction between science and technology

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Students' Epistemological Awareness Concerning the Distinction between Science and Technology

Abstract

We have developed an approach for assessing students' understanding about the distinction between science and technology. The assessment approach focuses on a specific aspect of this distinction, namely the different goal pursued by each of the two domains. Based on this approach, we collected data from two sources; two written tests administered to 183 elementary, 132 middle school and 78 elementary education students and follow-up interviews with a sub-sample of the participants. The findings that have emerged from the data analysis indicate that students of all ages commonly fail to distinguish between the goals pursued by science and technology. They also suggest that students possess a vague notion of the two domains in that they tend to draw on a wide variety of criteria to distinguish between them in a non-systematic and inconsistent manner. Our data also suggest that age and education level do not seem to have a significant impact on the validity and systematicity of students' response patterns concerning the distinction between science and technology. The study concludes by reporting the various epistemological difficulties that seem to influence participants' attempts to differentiate and explore the interconnections between the two fields. Our assessment approach can be used in studies or educational interventions that seek to monitor student understandings about science and technology. The findings can be used to inform possible attempts for designing or modifying activity sequences that address this particular aspect of epistemological awareness.

Keywords: distinction between science and technology, students' conceptions of the nature of science and technology, evaluation of epistemological awareness

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Introduction

The development of epistemologically informed views about the nature of science is widely recognized as a core learning objective of science education (AAAS, 1989; Driver, Leach, Millar, & Scot, 1996; Kang, Scharmann, & Noh, 2005). There is a need for additional research so as to better understand how to promote this as well as the various parameters that become relevant to this endeavour (Lederman, 1992; NRC, 1996). This need is specifically reflected by the fairly limited efforts in developing research-based teaching and learning materials to promote epistemological awareness (Lederman, 2007), especially in the case of the elementary and middle school grades.

This paper is embedded within a research project that sets out to contribute towards addressing this need in the context of a specific domain. In particular, it seeks to develop and validate teaching and learning materials to help students, aged 11 to 15, develop awareness with respect to the role of science and technology in society and to appreciate their distinction and their interrelationships. The selection to focus on this particular topic can be justified for various reasons. Firstly, it is recognized as an important aspect of the nature of science (McComas, 2008; Osborne, Collins, Ratcliffe, Millar, & Duschl, 2003). Secondly, it has not been adequately studied thus far, especially in the case of elementary and middle school students (Akerson & Volrich, 2006; Kang et al., 2005). Thirdly, realising the potentials and constraints of the two domains is of great importance for developing the ability to effectively engage with socio-scientific issues (Sadler, 2004; Zeidler, Sadler, Simmons, & Howes, 2005), which is recognized as an important component of both scientific and technological literacy (AAAS, 1989; Jones, 2006; ITEA, 2000, 2003; Kolstø, 2001, 2008; Sandoval, 2005). Fourthly, new knowledge in this area could inform and facilitate attempts to devise mechanisms for increasing students' interest towards science and technology courses (Gago, et al., 2004; NSF, 2003; OECD, 2006; Roberts, 2002) and it could offer them guidance on

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future careers. More specifically, it could help the education system to encourage students to make more informed decisions and this could, in turn, increase the likelihood for successful career choices. Finally, the prevalent conceptions about science and technology are important for efforts to communicate publicly their role in society and the outcomes of the various policy procedures for developing funding priorities. For instance, the level of public support for an innovation system in close symbiosis but distinct from the science system, and also closely related with financial investment mechanisms, is directly related to the level of public understanding of the differences between science and technology and the diverse roles they play in economic development.

The development of mechanisms and instruments for measuring students' epistemological understandings has been recognized as an important avenue for future development in science and technology education (De Vries, 2006; Lederman, 2007; Osborne & Dillon, 2008). This type of work can provide support for a necessary shift in emphasis from only assessing conceptual understanding to also assessing epistemological meanings (McComas, 1998). In this sense, specific assessment instruments can be useful to researchers and educators interested in exploring ways to engage students with more wholesome approaches to science learning than what is conventionally possible. Likewise, such approaches can enhance the depth of student understanding and can also empower them to make more informed choices about future study and careers (Sandoval & Morrison, 2003).

The study reported in this paper sought to investigate students', aged 11 to 15, and pre-service teachers' ability to distinguish between science and technology. It specifically focuses on the appreciation of the different goals pursued by these domains as an indicator of this ability. We used this indicator to develop a mechanism for assessing students' understanding of the difference between science and technology and to investigate the following research questions:

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1. To what extent do elementary, middle school students (aged 11 to 15) and pre-service teachers appreciate the distinction between science and technology in terms of the goals they pursue and how do the prevalent conceptions of these three groups compare?

2. What epistemological difficulties do elementary students and pre-service teachers encounter in their attempt to differentiate between science and technology and how do the difficulties across these groups compare?

Theoretical Framework

What is Science, what is Technology, and how do they Relate? Inputs from History.

The nature of science and technology are still being debated in philosophy. However, there are settled aspects of this debate, which we would like students to understand. One of these pertains to the idea that science and technology constitute two closely linked areas of human activity, which are strongly interdependent. Despite this strong connection, they represent clearly discernible domains of human enterprise, in that they serve entirely different social purposes. *Science* aims at producing reliable knowledge about how systems function; *technology* seeks to generate solutions to problems encountered by society or to develop procedures or products that meet human needs (AAAS, 1989; Agassi, 1980; Arageorgis & Baltas, 1989; Custer, 1995; Gardner, 1993, 1994; ITEA, 2000; Jones, 2006; NRC, 1996). In short, science is the enterprise that seeks to generate reliable knowledge; technology is the enterprise that seeks to respond to human needs by developing solutions to problems. From a methodological viewpoint, investigation is a core process in science; design is a core process in technology (Lewis, 2006; NRC, 1996).

A common perspective on the relationship between the two conceives of *Technology as Applied Science (TAS)*. This view implies a unidirectional relation, according to which developments in science provide the basis for the invention of new technologies (Gardner,

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1992; Layton, 1993; Layton, 1976). The essence of this position is illustrated by the following excerpt from the statement of Vannevar Bush, US presidential advisor on science policy, in 1945:

> *'Basic research leads to new knowledge… It creates the fund from which the practical applications of knowledge must be drawn. New products and new processes… are founded on new principles and new conceptions which in turn are painstakingly developed by research in the purest realms of science' (Bush, 1945, pp. 13-14 in Layton, 1993, p. 25).*

This perspective, which is commonly promoted by some science textbooks (Gardner, 1993, 1999), is invalid for two important reasons. The first rests on the idea that technology does not necessarily depend on science. The history of technology provides several examples demonstrating that technological invention (such as stone and metal processing, the textile industry) can precede, and hence, can occur independently of, any systematic activity in science (Arageorgis & Baltas, 1989; Basalla, 1988; Cardwell, 1994; Gardner, 1997; Gil-Perez et al., 2005). The second reason is that TAS is a biased viewpoint that conceives of science as contributing to technological development, totally neglecting the important contributions that run in the reverse direction. The history of science provides numerous examples illustrating how technological inventions can contribute to scientific progress. One of these relates to the technologically designed apparatus used by Galileo and the measurement techniques he invented in order to study freefall (Bunch, 2004; Drake, 1980). Another example relates to how the development of the telescope by craftsmen, much earlier than the emergence of our understanding of the corresponding optical phenomena, provided scientists with the ability to conduct more detailed observations and to develop an improved understanding of the solar system.

It seems that a more valid perspective for the relation between the two domains extends TAS in a manner that appreciates a bi-directional relation, in which each domain is both informed by and informs the other. Removing all the technological equipment from physics laboratories precludes any experimental activity and, hence, diminishes the interaction between theory and experiment, which is a crucially important component of the scientific endeavour. Likewise, the sophisticated instrumentation that is now assumed in designing experiments in many scientific disciplines would not have been possible without the proliferation of scientific knowledge in a variety of domains from electronics to psychometrics.

Students' Views of Science and Technology: What do we Know?

While students' epistemological beliefs about both the role of science and technology in society have been amply investigated (Carey, 1989; Elder, 2002; Kang et al., 2005; Liu & Lederman, 2007; Ryan & Aikenhead, 1992), it is important to note that, for the most part, they have been studied separately. Thus, while research has led to important insights into students' understanding of the nature of either science or technology, their understanding of the distinction and relation between these two domains is far from being adequately investigated. Below, we provide a brief overview of the main findings that have been reported in the research literature student understanding of the nature of science and technology.

How do students conceive of science? The available research evidence demonstrates that students hold an unarticulated notion of science as an enterprise. In particular, they tend to identify science with specific terms such as 'discovery' and 'experiment' (Carey, 1989; Elder, 2002; Ryan & Aikenhead, 1992) and fail to appreciate science as a field of study aiming at the attainment of better understanding of the world. Other studies suggest that students conceive of science as an attempt, which aims at improving the quality of our life (Custer, 1995; Liu & Lederman, 2007; Scherz & Oren, 2006). This view seems to be

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reinforced by the tendency of the mass media to place technological innovations under the umbrella of the scientific realm (Custer, 1995; Kang et al., 2005; Ryan & Aikenhead, 1992).

How do students conceive of technology? Students tend to vaguely construe technology as a field that is somehow connected to the improvement of the quality of our life (Burns, 1992). students also tend to restrict technology to modern technological achievements, such as computers, and to exclude devices such as the catapult (Burns, 1992; Cajas, 2001; De Klerk Wolters, 1989; De Vries, 2005; Jarvis & Rennie, 1996; Scherz & Oren, 2006). Finally, another finding that warrants mentioning, relates to students' tendency to reduce technology to the end products that emerge and their failure to appreciate other important components of technology as a process, such as the important role of invention and creativity in the design process (De Klerk Wolters, 1989; De Klerk Wolters, Raat & De Vries, 1990; De Vries, 2005; Kang et al., 2005; Scherz & Oren, 2006).

How do students conceive of the relationship between science and technology? Research that specifically seeks to address this topic has been very limited and also constrained to high school or college students (Aikenhead & Ryan, 1992; Ryan & Aikenhead, 1992). This research line indicates that students typically possess invalid or, at best, inaccurate views concerning the distinction between these fields. In particular, they usually express ideas consistent with the TAS view, described above (De Vries, 2005; Rennie, 1987; Ryan & Aikenhead, 1992). Other findings suggest that students tend to consider the specific area of research as the criterion determining whether a research study belongs to science or technology. For instance, they tend to exclusively consider anything related to medicine or the environment as examples of research in science (Ryan & Aikenhead, 1992). In contrast, any studies related to electricity or structures are more likely to be categorized as examples of research in technology (Rennie & Jarvis, 1995).

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Approaches Used for Assessing Students' Conceptions about the Nature of Science (NOS) and the Nature of Technology (NOT)

The increasing awareness of the need to teach aspects of NOS and NOT has created the need to develop effective tools for describing students' epistemological beliefs. Such tools are essential for providing baseline data and enhancing the research-based knowledge that is needed to guide attempts for curriculum development (Andersson & Bach, 2005; McDermott & Shaffer, 1992). Assessment tools are also vital for providing information on students' learning gains as they interact with relevant learning environments (Krajcik & Czerniak, 2007). Lederman (2007), Lederman et al. (1998) and Rennie and Jarvis (1995) provide extensive reviews of the efforts undertaken to develop ways of measuring students' and teachers' conceptions about the NOS and NOT within the last 40 years. These reviews suggest that most of the assessment techniques that have been developed largely rely on forced-choice instruments such as multiple-choice or Likert scale tests (e.g., TOUS, WISP, STI, NOSS, NOST, VOST, NSKS for assessing NOS, and PATT for assessing NOT). The potential effectiveness of either of these types of tools has been put into question in view of the fact that 'students and researchers do not necessarily perceive the meanings of a particular concept in the same way' (Lederman, 2007, p. 866), nor are the interpretations of those scoring the test the same (Lederman et al., 1998). Other NOS assessment approaches have relied on interview protocols with open-ended items (Carey, 1989) that are often stated in a decontextualized and abstract manner (e.g., What is science?). Such items are not easily or uniformly interpreted by respondents. Similar NOT approaches are sometimes adopted in essays and interviews (Rennie & Jarvis, 1995).

These pitfalls and possible ways to alleviate them present a widely discussed topic in the literature and, clearly, there is much room for additional research so as to develop more effective and sophisticated approaches capable of capturing students' epistemological ideas

(De Vries, 2006; Ford, 2008; Lederman, 2007). An alternative assessment approach has been followed in the case of multiple-choice instruments whose candidate responses were empirically derived, rather than being imposed by test designers. In this approach, test designers undertake research so as to identify students' ideas for each item and they then generate alternative responses for each multiple-choice item so as to reflect these students' ideas. This approach is exemplified by the Views On Science, Technology and Society (VOSTS) instrument (Aikenhead & Ryan, 1992), which is appropriate for students of grade 11 or above. In addition to being asked to choose among alternative responses, students were also explicitly requested to explain their reasoning. VOSTS has been characterized as the most 'systematic attempt to develop a paper and pencil assessment of the nature of science' (Lederman et al., 1998, p. 345).

Other assessment approaches that are reported in the literature rely on interview-protocols that combine decontextualized and contextualized items (e.g., items embedded in topical socioscientific issues) (Smith & Wenk, 2006). Finally, another assessment approach includes combining written tests, consisting of open-ended items, with follow-up interviews, in which students are asked to clarify their responses (Lederman et al., 1998; Lederman, 2007; Smith, Lederman, Bell, McComas, & Clough, 1997). In this study, we have taken this latter approach as described in the next section.

Methodology

Instruments

The study seeks to address the research questions by combining data from two different sources, involving a pair of written tests and follow-up interviews. The tasks used in these data sources were specifically designed in the context of the present study.

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The two tests, were designed to include items that work in parallel and they were administered sequentially in one session. Each of these tests consists of 32 multiple choice items, with each item describing the main objective of a certain research project. Students were asked to categorise these descriptions using a given criterion. In the first test, they were asked to determine whether the stated objective of each project was more closely aligned with the goal of science, technology or neither. In the second test, they were asked to differentiate between projects whose objective either involved the improvement of our understanding with respect to the behaviour of some aspects of the natural world, or the development of solutions to problems encountered by society, or neither of these two goals. Noticeably, these two sets of criteria are equivalent in that the second set draws on the core objectives of science and technology. Underpinning the combined use of these two tests is the idea that students who are in a position to differentiate between science and technology in terms of the objectives they pursue would respond to both tests in a similar manner. Thus, the correlation of students' responses to the two tests was anticipated to assess their awareness of this specific aspect and, hence, provide a measure of their understanding of the distinction between science and technology, in general.

One could argue that the rationale underlying this assessment approach, especially in the first test, seems inconsistent with the intricate links between science and technology. This concern derives from the fact that science and technology function in close partnership and, therefore, it would not be valid to distinctly classify a research project in one of the two fields. This concern, however, is not relevant to the test and the classification that students are asked to perform. More specifically, students are not asked to classify each project as a whole; instead, they are asked to focus on the overall objective stated by each project and to determine whether that objective seems compatible with the goal of science, technology or neither. This point can be further illustrated using two examples of items included in the tests.

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The first relates to a research project whose objective includes the production of a vaccine against various dangerous viruses. This objective is technologically-oriented since it is aligned with the goal of technology to respond to human needs by developing solutions to problems. Clearly, realizing this goal largely depends on scientific research in that it posits the establishment of an appropriate background as to the characteristics of the targeted viruses. However, given that students were specifically instructed to focus on the overall objective of the project, it could be deemed valid to claim that this objective is technological in nature regardless of the extent to which it utilizes the outcomes or the processes or procedures of science. The second example relates to the investigation of the possible health hazards that stem from the use of microwave ovens. Following the same line of reasoning even though this project cannot be implemented without inputs from technology, including the establishment of appropriate instruments and techniques to measure relevant variables, it would still make sense to argue that its overall objective is scientifically-oriented, since it describes an attempt to generate reliable knowledge in this domain.

Another point that could serve to further accommodate the concern relevant to the appropriateness of the proposed testing approach is that the instrument is not intended to be used with experts and it certainly does not purport to provide classifications of expert interpretations of the distinctions between science and technology. Instead, its target audience is restricted to students and teachers and it is merely concerned with the evaluation of the extent to which they can differentiate between the objectives of science and technology.

Fourteen of the projects emphasized the struggle to better understand something through investigation and they were therefore more compatible with the broad goal of science. These projects fall under five thematic areas (weather, astronomy, environment, medicine, electricity). Fourteen projects were compatible with the goal of technology, and they emphasized the struggle to design a product (nine projects) or a process (five projects). These

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projects are classified in six thematic categories (improving human health, constructing or improving instruments, addressing environmental problems, preserving/enhancing the quality of life, improving human safety, improving machines). Finally, the remaining four projects pertain to domains of human activity, other than technology or science (e.g., decision making). Table 1 provides typical examples of test items. In addition to the multiple-choice items, the first test included an open-ended question, which asked students to explain how they would determine whether a given research project seems either technologically or scientifically oriented. The first test that uses *Formal Terminology* (science/technology), will be hereafter referred to as *FT*, while the second test that uses *Elaborated Definitions*, will be abbreviated as *ED*.

[Insert table 1 about here]

Issues of Reliability and Content Validity

In an attempt to attain an adequate reliability of the written tests, first versions of them, which consisted of only 12 items, were pilot tested with a large group of students (336 elementary and middle school students) and their responses were analyzed using the Rasch model (Bond & Fox, 2001). The results of this analysis (0.42 and 0.41 were the reliability estimates for cases in FT and ED, respectively) indicated the need to increase the number of items so as to improve the targeting between items and cases. As a result, the tests were significantly expanded so as to include 32 items. This was expected to serve towards increasing the reliability indices and minimizing the effect of the guessing parameter (Haladyna, 1999). Indeed, the Rasch analysis that was undertaken with the data that emerged from the administration of the revised tests yielded high reliability estimates. In the case of FT, Rasch model reliability estimates for items and cases were 0.97 and 0.79, respectively, while the corresponding estimates for ED were 0.99 and 0.70.

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In an attempt to evaluate the content validity and the underlying rationale of the two tests, they were reviewed by an expert who holds a doctoral degree in Physics, another who holds a doctoral degree in Materials Science, an expert in Design and Technology teaching and an expert in Mechanical Engineering. The four experts were asked to, firstly, complete the tests and, secondly, comment on the appropriateness of the items and the testing approach, in general. In completing the tests, the experts were asked to determine whether each project should be classified under the field of science, technology or neither, solely based on the goal it pursued. All experts agreed on the appropriateness of the rationale underlying the combined use of the two tests. They also provided useful comments with respect to the wording of some items and the coverage provided by the items. These comments were addressed through the replacement of two items and through minor changes in the wording of some other items.

Follow-Up Interviews

A number of the participants (approximately 10%) who completed the two written tests also participated in follow-up semi-structured interviews, which were conducted by one of the authors. Each participant was asked to respond (for a second time) to a selected sample of items included in the two tests and to explain his/her reasoning. In addition to this, in cases where the interviewer was able to identify inconsistencies (e.g., cases in which interviewees provided incompatible responses to the various items or responded differently compared to the written test), she explicitly confronted students with these discrepancies and asked them to elaborate on them. These interviews were intended to provide a more detailed account of the reasoning underlying the student responses. This was also anticipated to inform our interpretation of data from the open-ended question of the FT test, in which students were asked to explain their reasoning (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002).

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Participants

The written tests were administered to 183 elementary students (fifth and sixth graders), 132 middle school students (seventh and eighth graders), and 78 pre-service teachers (undergraduate students pursuing a degree in Primary Education). The groups of elementary students, middle school students and pre-service teachers will be hereafter abbreviated as E, M and P, respectively. Even though groups E and M include students from two different grade levels, (elementary students consisted of 71 fifth graders and 112 sixth graders, while middle school students comprised 82 seventh and 50 eighth graders), each is treated as a homogenous group. This was justified, on the grounds that students from the two different grade levels in each group answered similarly in more than 84% of the items. The total number of participants in the follow-up interviews was 36 (13 students from group E and 23 students from group P).

Data Coding and Analysis

Participants' responses to the written tests were coded on a dichotomous scale as either correct (1) or incorrect (0). Omitted responses or cases in which participants stated that a research project belongs to both domains were coded as incorrect. The coded data were then subjected to correlation analysis in order to examine the extent to which participants responded in a similar manner to the two parallel tests. As discussed earlier, the correlation coefficient provides an indication of students' ability to appreciate the distinction between the two fields. Analysis of variance (ANOVA) was also used on the estimates that were generated by the Rasch analysis in order to examine whether there are systematic differences between the FT scores of the three groups (E, M and P).

Responses to the open-ended question included in FT and also the interview data were subjected to phenomenographic analysis (Marton & Booth, 1997). Each participant's

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responses were carefully studied with the explicit purpose to identify and describe his/her underlying reasoning. This process led to the identification of the qualitatively different ways of distinguishing between the two fields. In an attempt to enhance the reliability of the data analysis, a significant part of the data (approximately 25%) was independently coded by two of the authors. This yielded a high degree of inter-rater reliability (79%), while discrepancies were resolved through discussions among the members of the research team. The remaining data were coded by one of the researchers while regular meetings were held to build consensus on how to categorize ambiguous cases.

Findings

To what Extent do Elementary, Middle School Students (Aged 11 to 15) and Pre-Service Teachers Appreciate the Distinction Between Science and Technology and how do the Prevalent Conceptions of these Three Groups Compare?

This question was dealt with through several *measures*. The *first* relates to students' performance on the FT test. The markedly low scores (17 out of 32 for both groups E, M and 22 out of 32 for group P) provide an indication as to the students' lack of understanding with respect to the distinction between the two domains. An analysis of variance showed that the effect of grade level was significant, ($F(4,388)=35$, $p<0.001$). Post-hoc analysis using the Scheffé criterion indicated that the performance of elementary and middle school students was similar, while pre-service teachers performed considerably better.

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A *second measure* relates to the coefficient of correlation between the scores of respondents to the two tests. Given that the two tests were conceptually identical, it was hypothesized that, had the participants appreciated the distinction between science and technology, the analysis would have yielded a very high correlation coefficient. This,

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however, was not confirmed since the correlation coefficients for all three groups were low (0.37, 0.54 and 0.45 for group E, M and P respectively, $p<0.001$).

The *third measure* concerns the analysis of participants' responses to the open-ended item included in FT. This analysis led us to identify six different categories of response, which are illustrated in table 2 along with typical student quotes. Chi-square analysis showed that there are statistically significant differences in the distribution of responses across these categories depending on grade level, ($\chi^2(10)=149$, $p<0.001$). The largest differences relate to categories 1 and 6. More specifically, category 1 included far more participants from group P while the converse effect applied in category 6. The main results for each category are discussed below.

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The first category includes students who distinguished the two domains in terms of the main goals they pursue (21.9%). This broad category is further divided into five sub-categories. These sub-categories differ with respect to the depth and level of detail. Students who fall into sub-category 1.1, provided the most valid responses, expressing the idea that science seeks to understand how the natural world functions, while technology intervenes in the natural world in order to invent solutions to problems and to address human needs. Sub-category 1.2 includes responses, which suggest that science seeks to explain why something happens, while technology tries to invent or construct something that can be used to solve a particular problem. Students in sub-category 1.3 express the idea that science tries to explain why something happens, while technology tries to construct or improve something. This sub-category differs from the previous one in that students do not refer to whether these constructions are expected to somehow contribute towards solving any problem. Sub-category 1.4 includes responses suggesting that science tries to study something, while technology tries to construct or improve something. Unlike students in the previous sub-categories, these students made a vague reference to the term 'study' without clarifying its

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content or the focus of such study. The fifth sub-category coincides with the TAS position, discussed earlier in this paper.

Sub-categories 1.1 and 1.2 include more pre-service teachers (7.4%) than elementary and middle school students (2.0%), while the reverse applies in sub-categories 1.3 and 1.4 (0.6% and 6.6% respectively). A possible explanation for this is that older students were more able to verbally explain their thinking than younger students. This was obvious in the follow-up interviews in that younger students had more difficulty in expressing their thoughts. Sub-category 1.5 includes considerably more pre-service teachers (2.7%, 3.8% and 14.1% of the total number of students for groups E, M and P, respectively) and this might suggest that the TAS perspective seems to be reinforced by the increased exposition of students to conventional educational practice (De Vries, 2006) and by the accumulation of experiences with everyday life.

Responses in the second category suggest that science and technology differ in that they focus on different areas of study. In particular, 15% of participants mentioned that a research project belongs to technology or science if it relates to artificial (e.g., microwave ovens) or natural entities (e.g., water), respectively, regardless of the specific aim of the project. Noticeably, the frequency of responses falling in this category are similar for groups E and M (7.4% and 5.3% respectively) and considerably higher than pre-service teachers (2.3%).

Participants who fall into the third category (15.8%) attribute the difference between science and technology to processes they consider specific to each field. The most frequently cited processes include the 'experiment' and the 'construction of artefacts' for science and technology, respectively. Even though it would be possible to draw a distinction between science and technology in terms of processes (i.e., investigation is a core process in science, while design is a core process in technology), students' responses did not reflect such an informed view. Instead, they were obviously influenced by conventional teaching practice in

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science and technology, which often emphasizes these specific processes (experimentation, constructions) and, hence, leads students to develop these narrow ideas (Gardner, 1999; Gil-Perez et al., 2005). It is important to notice that this category mainly consists of elementary students (12.2%), in line with current curricular emphases in the corresponding subjects in Primary Education.

The fourth category (21.6%) includes participants who have provided a rather vague account of the difference between science and technology. Interestingly, these responses tend to be more detailed in the case of technology, where in many cases participants simply mention examples of technical equipment. This observation could be attributed to the increasing exposure of participants to various technological inventions in their daily life (e.g., computers, television, mobile phones) (De Vries, 2005; De Klerk Wolters, 1989; Jarvis & Rennie, 1996; Scherz & Oren, 2006). This category can be further analyzed into five sub-categories. The first (4.1) includes participants who have provided separate and unrelated accounts of how they conceive of science and technology and, hence, failed to make any direct reference to their distinction or interrelationships. Interestingly, the distribution of the responses in this category does not seem to vary across the three groups (1.8%, 1.5%, 1.5%, respectively, for groups E, M, P). Sub-category 4.2, in which students make use of an insufficiently discriminating criterion, that is usually too specific, with limited application and sub-category 4.3, in which students refer to objects that they consider characteristic of the two fields, have been only found in groups E (3.6% and 2.3%) and M (2.5 % and 0.5%). This could be related to the comment made earlier concerning the older participants' greater ability to express their thoughts in writing. An interesting finding is that a number of students' responses (mostly from group M) use a criterion according to which science and technology are two different sides of the same coin (sub-category 4.4). This sub-category mainly consists of responses that refer to the term discovery for both of the two fields,

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without any indication as to whether they ascribe a different meaning to this term when it is applied to science or technology.

Participants included in the fifth category (7.6%) provided responses that did not relate to the question, involved circular reasoning, or were incomplete. The majority of these responses concern participants that belong to groups E and M.

[Insert table 2 about here]

The *fourth measure* that was used to address the first research question relates to the interview data. Specifically, we processed the transcribed data for each participant with the purpose to identify the criterion s/he invoked to decide whether each project should be classified under science, technology, or neither. Even though students were presented with the objective of each project, our data showed that they tended to employ a range of criteria well beyond the project's stated objective. The breadth and content of these criteria served as an indication as to their appreciation of the difference between the two fields.

This analysis led us to discern three prevalent categories of criteria, each category including different variations of the same reasoning approach (table 3). The first category pertains to distinguishing between the two domains depending on the goal pursued by each project. This approach appeared in five different form variations, all classified under *Criterion Category 1, in Table 3*. The first two variants refer to science as an effort to understand how nature works and as an effort to give answers/formulate conclusions, respectively. The other two, accordingly, refer to technology as an effort to invent useful products and find solutions to problems in order to improve the quality of human life. These four criteria would be deemed valid in that they draw on the goal pursued by the two fields. The fifth form, which is not valid, conceives of science as an effort to meet human needs. It is notable that standardised frequencies for the first four forms of the first criterion are equally

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low for both educational levels that participated in the interviews. Interestingly, there are students, mostly from group P, that hold the misconception that the ultimate goal of science is problem solving. This finding is also consistent with the interview date: sub-category 1.5 in the analysis of the open-ended question, which appears in Table 2, essentially reveals the same idea.

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The second set of criteria that interviewees used to differentiate between the two domains rests on the idea that the topic that is under study in a given project determines whether that project belongs to science or technology (Table 3: Criterion Category 2). For instance, this way of reasoning led students to classify projects that were concerned with medicine or referred to machines in science or technology, respectively, regardless of the specific goals of the projects. This set of criteria, all of which are invalid, appeared in seven form variants, as illustrated in table 3.

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The next category of criteria rests on the idea that the difference between the two domains stems from the processes that are mentioned in each project. More specifically, students who applied these criteria (Table 3: Criterion Category 3) assumed that certain processes are specific to either science or technology and, hence, a reference to any of these processes in a given project led students to determine how to classify the project under consideration. These criteria, led to invalid conclusions in that students constrained themselves to strictly associating references to certain processes with one of these domains (e.g., experiments with science and constructions with technology). Students in group E activated forms of Criterion Category 3 more often than students belonging to group P. This is consistent with the analysis of responses to the open-ended items (category 3, table 2).

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In addition to these three categories of criteria, we also identified some additional criteria, which were activated less frequently. In particular, some students determined whether to classify a project in science or technology depending on: (a) the extent to which it pursues an

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innovative goal (e.g., inventing a cure for a disease), (b) whether it involves decision making, (c) the perceived difficulty of the goal of the project, (d) its viability, (e) whether it is theoretical or experimental and (f) the potential contribution of the research project to society.

The 24 different forms (including the variants of the three main categories of criteria) and their relative prevalence are depicted in table 3. It is important to bear in mind that only four out of these 24 forms could be considered valid (the first four from the Criterion Category 1) and this is again indicative of students' lack of awareness with respect to the distinction between science and technology.

[Insert table 3 about here]

Table 4 explores the consistency between the categorization of students' responses to the open-ended item in FT and during the interview sessions. Five out of the six categories that resulted from the phenomenographic analysis of students' responses to the open-ended question in the FT, also appeared in the answers of the sub-sample that was also interviewed. Category 6 did not appear in the interview because students were obliged to give a response in this setting. This finding strengthens the reliability of our analysis of the students' responses to the open-ended question, since the intervening and face-to-face character of the interview process, facilitated students' accountability and, thus, enabled the collection of more detailed information.

[Insert table 4 about here]

A last point that should be noted relates to the comparison between the two groups of students. During the interviews, each elementary student activated on average 9.4 criteria, while the corresponding value for each pre-service teacher was 8.2, which could be interpreted as an indication of more coherent thinking. However, our analysis demonstrated

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that educational or other experiences did not seem to help students differentiate between science and technology in a valid manner. This is also related to the generally low achievement in the FT as discussed in a previous section of the results.

One interesting finding that emerges when this analysis is specifically constrained to the multiple choice items, is that students in group E on average activated 2.6 more criteria than students in group P (*M*=9, *SD*=2.9 and *M*=6.4, *SD*=1.7, respectively). The opposite holds when the analysis is done for the criteria activated in the case of the open-ended item (*M*=2.6, *SD*=1 for group E and *M*=3.8, *SD*=2 for group P). Therefore, students' responses to the open-ended question do not express the variety of criteria that were activated in responding to the multiple choice items because, especially younger students, tend to mention only a few of these criteria in free writing. Possible explanations for this are: a) students only mention the criterion (or criteria) that prevails in their thinking, or was used most frequently, b) they mention the criterion (or criteria) that was activated more recently.

A *last measure* that was used as an indicator of students' appreciation of the distinction between science and technology relates to the extent to which they classified the projects included in the interview protocol in a systematic manner. Towards this end, we studied the interview transcript for each participant with the explicit purpose to identify instances of inconsistency. These include cases in which a research project that was classified by a participant in a certain field (e.g., science) could have been classified in the other field (e.g., technology) using a different criterion that was mentioned by this same participant at some point throughout the interview. One example of inconsistency is shown below.

Project I:
Interviewer: *In this project they are trying to create a substance that acts against known viruses linked to cancer. How would you classify this project?*
Pre-service teacher: *In science because it has to do with human health.*

Project II:

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Interviewer: *In this project they are trying to find a way to remove harmful substances from drinkable water. What do you think about this?*
Pre-service teacher: *In this case they are trying to find something technological, so I think it's technology.*
Interviewer: *In the previous case (Project I) you said that it falls under science because it is related to human health. Do you think that this project relates to human health?*
Pre-service teacher: *Yes, but in this case the researchers are trying to find something that they will construct and does not exist in nature.*

This pre-service teacher classified the first project in science because of its connection to human health. The application of this same criterion to the next project, which also relates to human health, should lead to its classification under science, as well. However, this participant categorized the second project in technology on the grounds that the project referred to a human construction, which is quite another criterion.

This analysis indicated a high level of inconsistency (30.1% of the items in group E and 51.1% in group P), which provides a clear indication as to students' unarticulated notion of science and technology. While the measure of inconsistency in the case of pre-service teachers could have been inflated by the significantly greater number of criteria they mentioned, which increased the possibility of identifying inconsistencies, the analysis also shows that maturation and increased exposure to conventional educational practice in science does not seem to have a positive effect on whether students have developed a valid notion of science and technology. This is further supported by the fact that pre-service teachers often realized that they were using multiple criteria inconsistently. This is illustrated in the following excerpt from an interview transcript.

Interviewer: *Do you think that this project in which researchers 'are investigating the possibility to modify food so as to add substances known for their ability to act against certain viruses' and the project in which researchers are 'trying to find a way to remove harmful substances from drinkable water' are similar in any way?* (This interviewee had previously categorized the first project in science and the second one in technology)
Pre-service teacher: *Yes, they are similar in that both projects try to achieve something in order to help people. However, something in the first case led me to conclude that it belongs to science and… if I thought of each project a bit differently, I could have classified them in another way.*

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In addition to this, 13 out of 36 participants (1 elementary student and 12 pre-service teachers) explicitly stated their failure to discriminate between science and technology, as illustrated in the following quotes.

> *'I haven't clarified for myself what science and technology are and how they differ. I think they are closely connected. That's why I confuse them.'* (pre-service teacher)
> *'The borderline between science and technology is too thin and I can't really tell the difference.'* (pre-service teacher)
> *'…they are very similar and I confuse them.'* (pre-service teacher)

What Epistemological Difficulties do Elementary Students and Pre-service Teachers Encounter in their Attempt to Differentiate Between Science and Technology and how do the Difficulties Across these Groups Compare?

The interview data, as well as participants' written responses to the open-ended item in the FT questionnaire, helped us identify difficulties encountered by students in discriminating between science and technology. These difficulties could be organized around three general categories depending on whether they relate to NOS, NOT, or the interaction between the two fields. This distinction only serves as a means to organize the discussion and it does not imply that difficulties in one category are disparate from the difficulties in the other categories. These difficulties, and their relevant frequencies, are shown in figure 1. One general comment that should be made is that while some difficulties were more influential in one of the two groups of students, we found instances for each difficulty in both groups E and P.

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[Inert figure 1 about here]

One of the difficulties that fall in the first group relates to students' lack of understanding with respect to the role of experiments in science. This difficulty, which was more common in the case of elementary students, appeared in three different ways. The first relates to the

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view that experiments are carried out only in the realm of science and, hence, any project that refers to experiments falls under science. For example, a student said that *'when it (the project) has to do with experiments conducted in a lab, then it's science'*. The second pertains to the view that scientific knowledge is necessarily based on experiments. For example, some students said that *'It's science because they need to do experiments'*. 25.6% of the elementary students and 4.9% of pre-service teachers made statements reflecting one (or both) of these perspectives. The third way pertains to the role of observation in science. Specifically, some students held the view that projects that are restricted to observations and do not involve any intervention on the part of the researchers, do not fall in the realm of science. This difficulty appeared in a very small proportion of elementary students (1.9%).

Another difficulty relates to students' tendency to believe that producing knowledge does not present a worthwhile task unless this knowledge contributes to the common good, by providing solutions to social problems (E:9.6%, P:6%). The following quotes are indicative of this difficulty: *'Doing research in science just for understanding is neither enough nor useful in its own sake. This knowledge has to be used somehow for a specific purpose.'* and *'Science is when the researcher studies various phenomena or situations in order to come to some conclusions that will be used for another purpose, for example, to be used by technology to create other artefacts that improve our life.'*. This instrumental view of knowledge, albeit useful from the perspective of the public appreciation of science, precludes basic scientific research and disorients from the quest to appreciate the distinction between science and technology.

The third difficulty that relates to the NOS emerges from the conception of decision making as a practice that falls under science and is therefore exclusively done by scientists. For example, some students classified a research project that seeks to decide on the most appropriate location for a new desalination plant under science *'because they have to do* *different scientific studies'* or *'because it's just a decision concerning the location they are going to build the plant at, not how they will build it. The location will be decided by expert scientists'*. This difficulty was found in 1.9% and 1.6% of participants from groups E and P respectively.

A further difficulty of this category, which was found in 1.9% of the participants from groups E and 1.6% of the participants from group P concerns the unarticulated exclusive notion of the term 'natural world'. This difficulty was obvious in students' failure to conceive of technological constructs as entities that, despite being artificial, still obey the laws of the natural world. This is illustrated in the following quotes: *'how a machine works is not the job of science, it concerns only technology'*; *'the natural world covers objects that are free of human interference'*.

The last difficulty in this category, which appeared in both elementary students (0.6%) and pre-service teachers (1.1%) relates to equating the mere use of scientific knowledge with the practice of science per se. These students failed to appreciate the distinction between *generating* scientific knowledge and *drawing on* scientific knowledge, which any literate citizen might be expected to do. A typical quote illustrating this difficulty is: '*I believe that exploiting knowledge is an example of research in science*'.

The second group consists of five difficulties, which are connected to the NOT. The first concerns the confusion between *using technology* and *doing research in technology* (E:16.7%, P:26.1%). Noticeably, this difficulty, which is illustrated in the following quotes, was the most prevalent in pre-service teachers.

> *'When the use of machines is involved, we are talking about research in technology.'*
> *'This is technology because we use computers.'*
> *'It's technological research because it concerns a technological artefact.'*

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The second difficulty relates to students' failure to appreciate creativity as an integral component of research in technology and to solely attribute this to science (E:14.1%, P:12.6%). This is demonstrated in the following quotes from students' responses:

> *'When they are trying to find a new way of doing something, it's science; when they are just constructing something we already knew how to do, it's technology.' (elementary student)*
> *'It's science because we are trying to find a way to remove substances from water. Even though they might use technology to do this it is not enough. They need to find out how to do this and this is science.' (pre-service teacher)*

The next difficulty pertains to students' notion of *technological constructs*. In particular, students often hold a vague idea of what this term means and they often restrict its scope so as to only include mechanical (e.g., cars) or electrical (e.g., computers) artefacts. This, in view of students' tendency to identify technology with technological artefacts led them towards expressing invalid reasoning, for instance, failing to recognize vaccines as technological constructs. This difficulty was identified in the responses of 9% of elementary students and 5.4% of pre-service teachers, and it is illustrated in the following quotes:

> *'In order to create the vaccine they use medical knowledge, so it is science. It could be technology given that they use machines to produce them.' (pre-service teacher)*
> *'…drugs are not technological products, they are not machines.' (pre-service teacher)*

Students' confusion between technology and manufacturing was another difficulty related to the NOT (E:4.5%, P:1.6%). Below is a relevant quote from a pre-service teacher's response when asked to say whether trying to develop a substance that acts against known viruses linked to cancer is an example of science, technology or neither:

> *'Well, all of the theoretical effort to find the cure belongs to science and when constructing it, it will be technology.'*

The last difficulty that relates to the NOT is the view of decision making as a problem solving process and hence, an example of technology. For example, a pre-service teacher said that *'determining the most appropriate location for the new water desalination plant is a*

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problem solving situation and, hence, it belongs to technology'. This difficulty also indicates the students' failure to identify design (of products or processes) as a core process in technology (De Vries, 2006).

The third group consists of two difficulties that are concerned with students' failure to appreciate the interaction between science and technology. The first relates to the view of technology as applied science, where science corresponds to the theoretical knowledge, while technology corresponds to the application of this knowledge. This is demonstrated in the following statements of two pre-service teachers:

> *'Science is mainly theoretical and it studies how something needs to be done. Technology puts this into practice.'*
> *'Technology uses findings from science such as the various laws in order to construct artefacts. For example, science has explained how light and mirrors function while technology has used this knowledge to construct the periscope.'*

This difficulty was more common in pre-service teachers (11.4%) than elementary students (1.3%) and this effect was also identified in students' responses to the open-ended item (subcategory 1.5, table 2) and in the prevalence of the corresponding criterion (fifth criterion of the first group of criteria, table 3)

The second difficulty relates to students' tendency to differentiate between the two domains depending on whether they refer to natural (science) or artificial (technology) entities (E:3.2%, P:4.9%). The following statements of two pre-service teachers' are revealing of this difficulty:

> *'I chose science because it has to do with water, which is a natural resource and therefore belongs to science.'*
> *'Technology has to do with something artificial, while science has to do with things that are not artificial.'*

Teaching Implications

The core finding that emerged from this study is that students, regardless of age, possess invalid and unarticulated ideas concerning the distinction between science and technology.

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Some of the main findings that are indicative of this lack of awareness include: (i) the use of very diverse, and often invalid, criteria to differentiate between science and technology, (ii) the unsystematic and often incongruent application of these criteria, and (iii) the various difficulties that undermine students' attempts to clarify the distinction between science and technology. The fact that these findings were identified in both groups of participants in the interviews, indicates that interaction with the conventional educational system, maturation and increased acquisition of experiences as members of society do not help students develop epistemological understanding with respect to the role of science and technology in society, their distinction or their interrelationships. This is in line with other studies reported in the research literature, which suggest that epistemologically informed ideas do not emerge spontaneously (Sandoval & Morrison, 2003) and that they should be treated as a significant learning objective that has to be explicitly addressed through specifically designed learning environments (Akerson & Hanuscin, 2007; Khishfe & Abd-El-Khalick, 2002; Lederman, 2007). This perspective is also consistent with another aspect of our findings: the high frequency of the invalid conception of technology as applied science, especially in the case of pre-service teachers, could be attributed, at least partly, to the fact that in some cases this idea is explicitly taught (De Vries, 2006) and it is found in science textbooks (Gardner, 1993, 1999).

Another important implication that emerges from this study relates specifically to science teacher education. Our results suggest that pre-service teachers themselves hold epistemologically naive ideas about science, technology, their distinction and interrelationships. From a technology education viewpoint, such findings are not unexpected, taking into account that technology education is a relatively new curriculum area, and therefore teachers have limited valid conceptualizations of the nature of technology (Jones, 2006). This highlights the need for professional development so as to help teachers become

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more knowledgeable and also more capable of acting as designers and organizers of appropriate learning environments that will help their students engage in epistemological discourse and develop more informed ideas (Lederman, 2007).

Concluding remarks

Two main contributions emerge from this study. The first, which is technological in nature, relates to the assessment approach that has been developed and used in this study to investigate the extent to which students appreciate the distinction between science and technology in terms of the objectives they pursue. This contribution is directly relevant to the need that is recognised in the literature for new assessment techniques and instruments regarding students' epistemological ideas, especially in the case of the elementary and middle school grades (De Vries, 2006; Lederman, 2007). Even though the assessment instrument reported here only constitutes one step towards addressing this need, we do believe that it could contribute to the relevant discussion that is documented in the science education research literature. In addition to this, we also hold that it could be useful to educators and researchers interested in exploring a shift from the conventional emphasis on conceptual understanding to include assessments of students' appreciation of the NOS and the NOT.

The second contribution, which is scientific in nature, relates to the findings on students' awareness about the distinction between science and technology and the various difficulties they encounter in this respect. These findings could serve to extend the research-based background knowledge needed to guide and inform the process of designing and developing learning materials in this particular domain.

As discussed earlier, this study is part of a broader research project, which seeks to design, develop and validate teaching and learning materials for helping students in the age range 11 to 15 to develop an awareness of the role of science and technology in society and

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also of their distinction and inter-relationships. The findings that have been presented in this study encourage the orientation of this project in that they indicate the need for such teaching and learning materials. In addition to this, the identified student difficulties also inform the process of designing the curriculum materials so as to devise activities that provide students with guidance to resolve them.

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Submitted

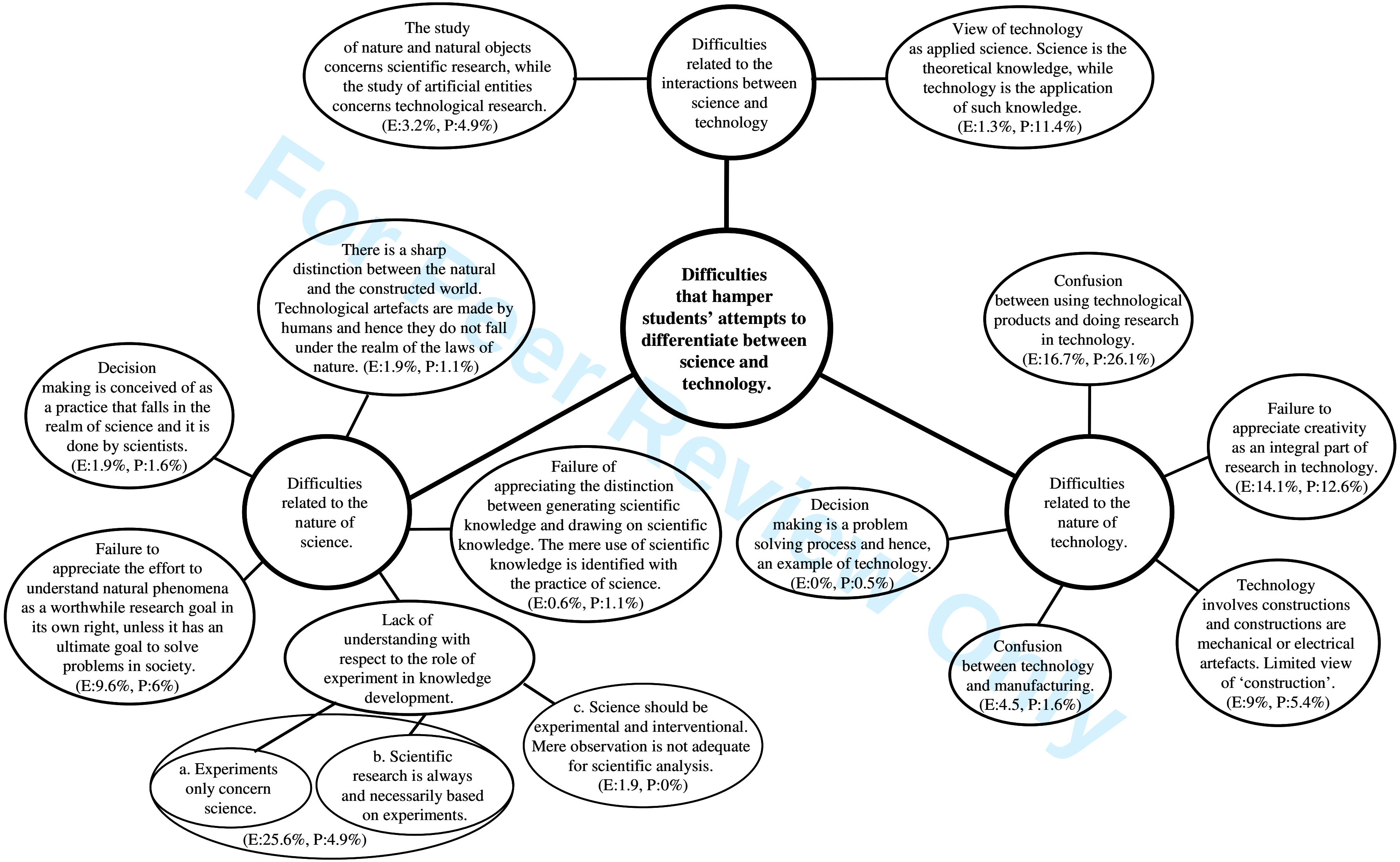

Figure 1. Difficulties that hamper students' attempts to differentiate between science and technology

Table 1

Design of the two tests and typical examples of research efforts

	Thematic category	Typical examples of research efforts
SCIENCE	Weather	We try to explain how lightning is created.
	Astronomy	We observe the sky through telescopes in order to study the motion of planets.
	Environment	We are studying a newly located species in a park, in order to see how it differs from the other known species living in the same park.
	Medicine	Antibiotics help us in confronting some diseases; however, too frequent use of antibiotics can be detrimental to our health in the long term. We try to understand better what types of problems may be caused by overuse of antibiotics.
	Electrical devices	We examine whether microwave ovens are dangerous for our health and also what sort of problems they might cause.
TECHNOLOGY	Improving human health	We try to create a vaccine against various dangerous viruses.
	Constructing or improving instruments	We try to improve microscopes so that we can make more detailed observations.
	Addressing environmental problems	We try to make filters to absorb polluting fumes that are emitted from factory chimneys.
	Preserving / enhancing the quality of life	The raw materials that are normally used for producing electricity are oil and coal. The amounts of these materials are continuously diminished, so we try to develop new plant based materials for producing electricity.

	Improving human safety	We try to make an artefact that will protect us from lightning.
	Improving machines	We try to design faster aeroplanes.
OTHER	Measurement and monitoring	We take monthly water flow measurements of natural streams.
	Decision making	We are trying to decide the best location to build a desalination plant.

Table 2

Phenomenographic analysis of the responses to the question ‘When does a research project belong to science and when does it belong to technology?’

Categories of response	Frequencies and *percentages*			
	All	E	M	P
1. Discriminating based on the goal of each field.	86 *21.9%*	38 *9.7%*	6 *1.5%*	42 *10.7%*
Subcategory 1.1: Science tries to understand how the natural world functions. Technology tries to intervene on the natural world by inventing solutions to problems and meeting human needs. *‘A project belongs to science when it deals with natural phenomena and studies them in depth to establish theories and conclusions. A project belongs to technology when it tries to find solutions to address human problems and improve our life conditions.’*	21 *5.3%*	4 *1.0%*	0	17 *4.3%*
Subcategory 1.2: Science tries to explain why something happens. Technology tries to invent or construct something useful, that solves a particular problem. *‘A project belongs to science when the goal is to discover knowledge or the truth. A research study belongs to technology when it tries to construct something that will solve a specific problem, utilizing scientific knowledge.’*	16 *4.1%*	3 *0.8%*	1 *0.2%*	12 *3.1%*
Subcategory 1.3: Science tries to explain why something happens. Technology tries to construct or improve something.	5 *1.3%*	4 *1.0%*	0	1 *0.3%*

'A research project belongs to science when we are trying to find out why. It belongs to technology when we have to design or construct an artefact.'				
Subcategory 1.4: Science tries to study something. Technology tries to construct or improve something. *'It's about science when they try to investigate different things. It's about technology when they try to construct different things.'*	23 *5.9%*	22 *5.6%*	0	1 *0.3%*
Subcategory 1.5: Science tries to explain why something happens in order to find the solution to a problem and help mankind. Technology tries to implement this solution or to contribute towards developing this solution through some construction. *'Science: when we want to investigate a phenomenon and give solutions to a problem. Technology: constructing instruments, when we want to implement the solutions we thought of.'*	21 *5.3%*	5 *1.3%*	5 *1.3%*	11 *2.7%*
2. Discriminating based on the object of study in each field.	59 *15.0%*	29 *7.4%*	21 *5.3%*	9 *2.3%*

Science deals with the natural environment (objects not made by humans), while technology deals with the artificial environment (objects built or improved by humans). *‘When it relates to a living organism, the research belongs to the field of science. But when it relates to electronics or stuff made by people, then it belongs to the field of technology.’* *‘A research project belongs to science when it relates to the natural environment. A research project belongs to technology when it relates to machines and constructions.’*				
3. Discriminating based on the methods that appear in each field.	62 *15.8%*	48 *12.2.%*	10 *2.5%*	4 *0.1%*
Reference to experiments, observations, predictions, etc. as methods used in science. Reference to constructions, calculation, measurements, etc, as methods employed in technology. *‘A project belongs to science when we do an experiment.. A research project belongs to technology when we construct something.’* *‘A research belongs to science when we will measure something, e.g. the temperature of the fridge. It belongs to technology when we construct airplanes and electrical devices.’*				
4. Inadequate or ambiguous discrimination.	85 *21.6%*	37 *9.4%*	33 *8.4%*	15 *3.8%*

Subcategory 4.1: Use of two qualitatively different criteria, one for each field. *'A research project belongs to science when it deals with health and environmental issues. A research project belongs to technology when it tries to solve problems.'*	19 *4.8%*	7 *1.8%*	6 *1.5%*	6 *1.5%*
Subcategory 4.2: Use of an insufficiently discriminating criterion, which is too specific, with limited application. *'Things that deal with our health belong in science. Technology is more about buildings, cars, what people do to have a better life.'*	24 *6.1%*	14 *3.6%*	10 *2.5%*	0
Subcategory 4.3: Reference to objects that are considered to characterize the two fields. *'Wood is in technology because we make furniture. Wires and batteries are in science.'*	11 *2.8%*	9 *2.3%*	2 *0.5%*	0
Subcategory 4.4: Use of a criterion in a way that the two fields match. *'Science: when we try to improve something and discover something new with the help of experiments. Technology: when we try to discover something new, that simplifies and improves our lives.'*	*24* *6.1%*	*4* *1.0%*	*12* *3.1%*	8 *2.0%*
Subcategory 4.5: Too general and insufficient descriptions. *'Technology is something that develops, while science is something that we discover.'*	7 *1.8%*	3 *0.8%*	3 *0.8%*	1 *0.2%*
5. Irrelevant answers	30 *7.6%*	21 *5.3%*	7 *1.8%*	2 *0.5%*

(i) The answer does not respond to the question (ii) The answer involves circular reasoning or tautologies (iii) The answer refers only to one of the two fields *'When a research can be solved only with science, then it belong to science. When the problem is solved only with technology, then it belongs to technology.'* *'In science we do scientific stuff and in technology we do technological stuff.'*				
6. No response	71 *18.1%*	10 *2.5%*	55 *14.1%*	6 *1.5%*
Total	393 *100%*	183 *46.6%*	132 *33.6%*	78 *19.8%*

Table 3

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Prevalence of criteria activated during the interviews

	All	E	P
1. Criteria that refer to the objectives of a research project	*34.4%*	*24.4%*	*35.9%*
It belongs to *science* when there is an effort to understand how nature works.[1]	2.7%	2.6%	2.7%
It is *science* when the ultimate goal is problem solving and meeting human needs.	7.7%	6.0%	9.6%
It belongs to *science* because of the attempt to give answers and formulate conclusions.	8.5%	8.3%	8.7%
It belongs to *technology* when there is an effort to find solutions to problems in order to help humanity and improve human life.[1]	7.7%	7.7%	7.6%
It belongs to *technology* because of the effort to invent and implement a useful construction.	8.0%	4.5%	10.9%
2. Criteria that refer to the study field of a research project	*64.1%*	*55.8%*	*71.2%*
It belongs to *science* because it deals with human health.	3.2%	0.0%	6.0%
It belongs to *science* because it refers to natural entities.	6.5%	9.0%	4.4%
It belongs to *science* because it is about physics or medicine or maths or ecology or geography or biology.	22.9%	7.7%	35.9%
It belongs to *technology* because it has to do with a machine or a piece of apparatus or an object or an artefact.	16.2%	15.4%	16.8%
It belongs to *technology* because it concerns artificial entities (human construction).	9.7%	12.2%	7.6%

Neither science or technology because it belongs to physics or medicine or math or chemistry or ecology or meteorology.	5.3%	10.9%	0.5%
Neither science or technology because conducting experiments or trying to understand something concerning technological artefacts cannot be either science or technology.	0.3%	0.6%	0.0%
3. Criteria that refer to the processes of a research project	*69.4%*	*77.6%*	*62.5%*
It belongs to *science* because it contains investigations or studies or experiments[2] or observations or predictions.	33.5%	39.1%	28.8%
It belongs to *technology* because it contains processes of design or construction[3] or improvement or evaluation.	26.5%	37.8%	16.8%
It belongs to *technology* because there is use of a technological artefact.	9.4%	0.6%	16.8%
4. Other criteria			
a. Criteria that refer to the novelty of a research project	*5.3%*	*8.3%*	*2.7%*
It belongs to *science* because it refers to areas that we don't know much about.	5.3%	8.3%	2.7%
b. Criteria that refer to the role of decision making in a research project	*2.1%*	*2.6%*	*1.6%*
It belongs to *science* because knowledge utilization is necessary in order to make a decision.	1.2%	1.3%	1.1%
It belongs to *technology* because technological knowledge is needed in order to meet human needs by making the right decision.	0.9%	1.3%	0.5%
c. Criteria that refer to the level of difficulty of a research project	*2.1%*	*1.9%*	*2.2%*
It belongs to *science* because it is a very difficult study.	1.5%	1.3%	1.6%

It belongs to *technology* because it is not a very difficult study.	0.6%	0.6%	0.6%
d. Criteria that refer to how theoretical or practical a research project is	*5.9%*	*0.6%*	*10.3%*
It belongs to *science* because it is a theoretical effort.	3.5%	0.6%	6.0%
It belongs to *technology* because it is a practical application (something tangible).	2.4%	0.0%	4.4%
e. Criteria that refer to how realistic a research project is	0.6%	1.3%	0.0%
Neither of the two fields because the particular project is not feasible.	0.6%	1.3%	0.0%
f. Criteria that to the utility of a research project	*0.3%*	*0.6%*	*0.0%*
Neither of the two fields because the particular project has no useful effect.	0.3%	0.0%	0.0%

[1] Criteria that are considered as discriminating of science and technology

[2] The most frequently mentioned process of science (16.2%, 23.7%, 10%)

[3] The most frequently mentioned process of technology (18.8%, 27.6%, 11.4%)

Table 4

Comparison between the categorization of students' responses (open ended question)[1] in the FT test and in the interview for the open ended question[1]

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Categories of open ended question	FT (n)	Interview (n)
1 (goals)	16	8
2 (study focus)	2	2
3 (processes)	4	7
4 (insufficient or ambiguous discrimination)	8	14
5 (irrelevant answer)	1	1
6 (no answer)	1	0

[1] Data are only drawn from the 32 students that participated both in the interviews and in the tests