Integrating Science and Technology in School Practice Through the Educational Reconstruction of Contents

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1 Introduction

There is a growing consensus amongst Science Education researchers that complex challenges of industrialized societies demand curriculum designers to empower students with conceptual and practical tools to let them become active citizens and not only passive consumers of knowledge products (DeBoer 2011; Bencze and Carter 2011). These tools have been grouped under the 20 or more years old slogan of Scientific Literacy (SL). According to Sadler and Zeidler (2009),

> the phrase has become ubiquitous in our field and represents what we expect students to know and be able to do as a result of their science learning experiences. (p. 910)

Roberts (2007) divides into two broad categories the manifold conceptions of SL:

1. The first (Vision I) promotes the learning of de-contextualized science knowledge (i.e. concepts, processes, structure) and is essentially related to traditional approaches where scientific contents come first, while some brief reference to applications are made at the end (Bennett et al. 2003). These approaches have gained some criticism since they may transmit a distorted and impoverished view of science which can negatively affect conceptual learning (Gil-Pérez et al. 2005).
2. The second (Vision II) entails those approaches which aim at helping students develop and master high-level reasoning skills as decision making (Sadler and Zeidler 2005a), argumentation (Jiménez-Aleixandre and Pereiro-Muñoz 2002), reflective judgment (Zeidler et al. 2009) in order to use scientific knowledge in

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different science-related contexts of their own life (health, environment, …). Vision II is therefore basically related to a situated learning perspective in which: *"knowing and learning cannot be abstracted from the environments in which they take place"* (Sadler 2009, p. 3).

We clarify that the key distinction between Vision I and II relies on the word *context* since it focuses, rather than on Science inner world, on the relationships between Science and the real world.[1] To the widest extent, society *is* the broadest context in which Vision II of SL may fulfil its aims since decision-making, argumentation and reflective judgment are all activities that make sense when a plurality of individuals share a common background and are called to deal with controversies in a non-violent and cooperative way. However, relationships amongst individuals and between individuals and Society are increasingly mediated (for instance, in communication processes) by Technology, which shares a reciprocal help relationships with Science. As a consequence, the meaning of *context* – an important aspect of SL Vision II – can be extended in a continuous manner by including the connections – Science, Society and Technology.

The Science-Technology-Society (STS) movement (Ziman 1980) started in the late seventies as an answer to dissatisfaction with some aspects of previous curricula reforms in science education (Fensham 1988) and purposefully addressed the interplay between Science, Society and Technology. Main aims of the STS curriculum were (Aikenhead 2007): to bridge the gap between science contents in the curricula and students' interests[2] in everyday life; to focus on the nature and image of science and of the scientific intellectual enterprise; to give high priority to students' preparation for a responsible and informed participation as citizens in social decisions involving scientific and technological themes[3] as environment, sustainable development and health.

[1] Science *is* developed by scientists within the real world and its main objective is the study of natural phenomena which happen in the real world. However, science knowledge is developed using the abstract language of mathematics and hence in its theories, models and processes are de-contextualized. The aims of such de-contextualization are to acquire the necessary level of reliability (Ziman 1978). We will return on the issue of reliability in Sect. 2 of this paper.

[2] Here "interest" is intended as an intrinsic motivational variable with three specific aspects: it is content specific; it is the result of an interaction between an individual and the surrounding environment; it has both cognitive and affective aspects (Lavonen et al. 2005; Hidi et al. 2004). For the sake of brevity we will not address the interest issue in this paper.

[3] A wider meaning to the students' participation to society as active citizens as far as Science and Technology are concerned is the dimension of professional careers. Recently Europe has witnessed students' waning interest in science and technology related careers (European Commission 2007; Nuffield Foundation 2008). There are many factors influencing the choice of a professional career as for instance (Lavonen et al. 2008): perceived values and images of Science and Technology; stereotypical views of scientific and technological occupations; perception of the difficulties about physics and mathematics; socio-cultural environment; quality of science and technology curricula; gender gap. For an overview of Italian students' choices of scientific studies at academic level see Pellegrini (2011). Although it is in some way related to the arguments of this paper, for the sake of brevity, this theme is not addressed here.

The STS movement pervaded the science curricula reform agenda until the mid nineties and later generated educational sub-movements, as STSE (E stands for environment)[4] and SSI (Socio-Scientific Issues).[5] STS approaches are somewhat diffused mainly in countries where didactical proposals were designed (e.g. the PLON project in Netherlands, Salters Advanced Chemistry/Physics in the UK, and Scope, Sequence and Continuity in US; for an extensive review see Aikenhead 2003) but they are still somewhat marginalized from the curriculum in other countries (Hughes 2000). In our opinion, this is related to the question: "do students *actually* learn Science through STS, STS(E) and SSI approaches?". Results from literature so far are somewhat contradictory. Bennett et al. (2007) claims that:

> the findings on understanding of science provide strong evidence that context-based/STS approaches provide as good a development of understanding as more conventional approaches. There is more limited evidence to suggest that understanding may be enhanced. (p. 16)

Aikenhead (1994a) also admits that:

> student achievement on traditional subject matter at the next level of science education (at a higher grade or at university) will not be significantly compromised by teaching science through STS.

Therefore, STS designers experienced a kind of *frustration* of their initial expectations:

> …one lesson that we learned as curriculum developers is that, in general, issues were dealt with [in the PLON project] too broadly. We were seduced in our first version materials in trying to deal with a complete issue, such as the Energy Problem or the Nuclear Arms Race. (Eijkelhof and Lijnse 1988, p. 467)

The issue is becoming more relevant in a world dominated by standardized assessments: poor results in students' achievements (OECD 2009; IEA 2011; NAEP 2011) may be really a valid reason to impede the diffusion of these movements in school practice.

Limiting the focus to the relationships between Science and Technology in the prospective of the implementation in school practice, from what discussed above, the following research questions arise:

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[4] The STSE movement aims at: promoting students' awareness of cultural aspects of Science and Technology; discussing the role of economics in scientific and technological decision; development of students' own ideas and values about scientific and technological progress; promoting active and conscious agency in society and politics (Pedretti and Nazir 2011).

[5] The SSI movement promotes students' involvement in learning science through controversial contexts that concern society (Sadler 2004). The dilemmas usually are embedded within a complex web which requires content knowledge related reasoning and arguments, explicit reflection on relevant epistemology aspects, personal connections at micro- (familiar), meso- (state citizenship) and macro- (human perspective) level with the issues. Consequently, to deal with SSI, environmental, economical, political, moral and ethical considerations are needed in order to provide students with opportunities to prepare them to act as active contributors to the life of the society which they live in (Zeidler et al. 2005).

- RQ1. What contents should be taught in approaches aimed at implementing an integration between Science and Technology?
- RQ2. How should these contents be treated to achieve an effective integration?

The aim of this paper is to answer to these questions by presenting and defending an overall framework which re-conceptualizes the Science and Technology integration at the educational level of Teaching-Learning Sequences (TLS, Meheut and Psillos 2004). A TLS embeds the close relationships between research and development of teaching activities at an intermediate level between the macro dimension of a curriculum and classroom micro-episodes. Two general aspects of TLS design and development, reviewed in the introductory chapter (Psillos and Kariotoglou, this volume), will be discussed in more detail here: (1) the epistemic dimension, to build the integration on important aspects of Nature of Science and Nature of Technology; (2) the reconstruction of content knowledge or didactical transposition, to identify a *common core* on which the Science and Technology integration is built. A third aspect, that of iteration as a means to improve and adapt an integrated TLS, will be the focus of our case study.

The structure of the paper is as follows: we first review previous efforts in integrating Science and Technology in educational research; then, we detail the main features of the proposed theoretical framework. Finally some teaching implications are discussed.

2 Previous Attempts at Integrating Science and Technology

While advocated from one hand as a central part of SL (AAAS 1989, 1993, 2001; NRC 1996; ITEA 2000), the role of Technology in science education seems controversial (Raizen 1997):

> STS courses developed by scientists and science educators express an entirely insufficient conception of technology. (p. 63)

So what is this not informed conception of Technology that emerges from science education approaches? Literature has revealed a wide range of approaches to deal with Technology from the perspective of Science Education.

Historically, STS approaches have followed the straightforward way of trying a balance between traditional science and more socially-oriented contents. This way of dealing inevitably leads to a loss of depth of the contents to be addressed. As reported by Aikenhead (1994b), two distinct but complimentary directions have been taken in developing curricula: on the one hand, the teaching of standard science contents embedded within a technological/social context to 'spice' them up; on the other hand, focus is mainly on students' critical thinking and attitudes toward science with a scanty attention to science and technology contents. Combinations of these two viewpoints have resulted in a heterogeneous compound of standard science and STS contents.

Gilbert (1992, p. 570) identified a cluster of approaches which could be categorized as "*education involving technological outcomes*" and intervention focused on "*the processes by which those outcomes are produced*". The first category encompasses *content-driven* approaches, the focus being on the science content; the second one entails *process-driven* approaches and was focused on the technological design.

Gardner (1994, 1999) proposed a categorization of the views of the relationships between Science and Technology from the epistemological viewpoint: Science precedes Technology or Technology as applied Science (De Vries 1996); Science and Technology are independent, Technology precedes Science, Technology and Science learn from each other. Basically, many STS approaches use technology only as context both from the Science viewpoint (technological devices are applications of physics laws) *and* the Society viewpoint (in terms of the social consequences of the use of a technological device).[6]

Craft-based, industrial production-oriented and high-tech approaches[7] are all examples of the demarcationist view of Science and Technology relationships in which basically Technology is taught independently of scientific knowledge.[8]

Design-based approaches are on the side of an integrated view (for a review related to the UK context see, e.g., Wilson and Harris 2004). Design is basically a circular process which involves four stages (Cross 2003; Banks and McCormick 2006): identifying needs and opportunities (1); generating (2), implementing (3), evaluating and re-designing (4) the solution. There are many conceptualizations of the design process with a growing level of complexity (Rennie et al. 1992) but research has mainly focused on if and how this practice may help science educators to engage students in more authentic hands-on activities and tasks (Crismond 2001) to learn more science content (Roth 2001; Fortus et al. 2004).

[6] Lavonen et al. (2005) argue that the role of technology in STS approaches declined with time since it is problematic from the viewpoint of gender issues. The main argument is that girls do not perceive technology as interesting as boys, being more interested in society problems as sustainable development and environment respect. While valuing this perspective, for the sake of brevity, the theme of technology in STS instruction from the viewpoint of gender issues is not discussed here.

[7] In some European countries and in Australia, in early nineties, the term technology education was replacing the term "industrial arts" (De Vries 1994). Many questions surrounded this trend in curricula change: was this new subject industrial arts renamed? Did it reflect new instructional content or methods? Will a new student population be served? (Herschbach 1992, p. 4). Generally, there was a fairly common consensus about the need for the introduction of a sort of technology education, whose main aims were essentially (Gilbert 1992, p. 568) to: prepare students for work in the technology industry; provide general literacy in order to prepare technology fluent citizens; learn about how technology is organized and its consequences for society. The first aim was borrowed from the former 'industrial arts', whereas the other two were new and inspired by the just born debate about the nature of technology (AAAS 1989).

[8] An example of this view can be found in the secondary school curriculum in Italy where, at compulsory secondary level (14–18 years), scientific and technological/vocational school streams are separated both in terms of contents and public perception.

Some recent findings suggest that design activities integrated by exemplar experiments aimed at addressing students' alternative conceptions can be particularly effective (Schnittka and Bell 2010), while other findings suggest that design activities alone do not guarantee an improvement of students' achievements in science (Levinson et al. 1997; Penner et al. 1998; McRobbie et al. 2000; Silk et al. 2009; Puntambekar and Kolodner 2005).

The effectiveness of design activities seems thus basically demanded to the ability of teachers to manage such an increased cognitive load into their practice. And, in the best case, what can be obtained is a successful *inclusion* of design activities into Science classroom. As a consequence, echoing the popular debate started in the '70s about Combined Science, Coordinated Science, Multidisciplinarity vs. Interdisciplinary (Richmond 1973; Black and Atkin 1996; James et al. 1997), integrated design-based approaches have gained the favour of some authors (Lewis 2006) but also have raised some criticism in defence of a status of Science and Technology as separate subjects (Carlsen 1998; Barlex 2002; Lewis et al. 2007).

Recently, scholars of the Science and Technology integration (Geraedts et al. 2006) have realized that the debate was mainly on the *degree of integration* of the two subjects (Layton 1988). This lead to neglection of the multi-dimensionality of the integration process, which includes: ways of learning, ways of knowing, skills, content, attitude and pedagogy (Berlin and White 1994). These authors hence called for a more coherent approach to support the broad aims of SL (AAAS 1993) supporting especially awareness of the nature of constituting disciplines and mutual coherence. Similar programs had been already proposed on the basis of cooperation between science and technology teachers in Israel (Barak and Pearlman-Avnion 1999), US (Beven and Raudebaugh 2004) and in Canada (Bencze 2001) focusing on a sort of double-track of scientific investigation and invention/design projects.

However, all these approaches seem to be born from the strive for legitimacy in school practice of Technology (Lewis 2006):

> …as school subjects, Science and Technology have had separate existences – the former being well established and bearing high status, the latter striving for legitimacy as valid school knowledge, its status often insecure. (p. 255)

and from the somewhat "private competition" with Science refuelled in some way by many standard associations calls for improving Technology Literacy (AAAS 1989; ITEA 2000, 2003).

Hence, while some of these authors (Barak and Pearlman-Avnion 1999) support the view that the

> separation between the areas in school curricular is often artificial. (p. 239)

acknowledging that (Cajas 2001):

> there is a common body of scientific and technological ideas and skills that is relevant for the education of all students. (p. 725)

they do not deal directly with the central question from the educational practice of how to use this common body and, more specifically, what kind of contents the students would learn from these integrated subjects (Yager 1996) taught by different teachers with sometimes different academic backgrounds.

3 Main Relevant Aspects of the Nature of Science in the Perspective of Integrating Science and Technology

To discuss our approach to the integration of Science and Technology from the content knowledge viewpoint, some reflections on the prominent epistemologies that shape current views of Nature of Science (NOS) should be pointed out. As argued in the introductory chapter (Psillos and Kariotouglou, this volume), the epistemic dimension in the design and development of TLSs in science education allows to analyse the structure of the contents to be taught, their theoretical underpinnings and their historical evolution. For this reason, NOS has often been acknowledged as relevant in SL (NSTA 1982). In particular, advocates (Abd-El-Khalick and Lederman 1998; Bell et al. 2000) support the claim that a learning objective of science education for all students would be the awareness of certain important aspects of NOS. Amongst these, there is consensus on (Lederman 2007): tentativeness[9] of scientific knowledge and reinterpretation of stable knowledge when new evidence is available; empirical research is informed by theory but also by scientists' personal creativeness; scientific knowledge is socially constructed through the instrument of peer review and cultural norms agreed in the scientific community.[10]

While valuable, these aspects say little or nothing about what actually should or can be done for integrating Science and Technology in the sense that we adopt in this paper. Some more specific discussion about the chosen aspects should be elicited from the research field about NOS to deal with the integration issue. To achieve such specificity, we will use as exemplary disciplinary scientific context Physics.

The first aspect concerns *how* the contents are established within Physics body of knowledge. With respect to this aspect, basically we ground our position on the work by Ziman (1978). Being Physics purposefully developed to use an unambiguous language as mathematics, the theoretical constructions that describe and interpret the natural phenomena should include measurable quantities, i.e., quantities to which it is assigned a number, and hence, it is the choice of such quantities that warrants the reliability of the physics results. Conversely, the reliability of scientific descriptions, interpretations and prediction of natural phenomena can be judged by the fact if measurable quantities are involved in this process.

As any other fields in Science, also Physics has its tentativeness in the selective sense summarized by Ziman (1978):

> Only a small proportion of the information contributed to science by research is eventually incorporated permanently in the body of scientific knowledge. (p. 130)

[9] Tentativeness implies the existence of controversies amongst scientists that may arise, e.g., from discrepancy between theoretical predictions and experimental observations and can be resolved with plausible modifications to the theoretical assumptions or with the development of completely new frameworks for interpreting them.

[10] Recently, SSI advocates had also called for the relevance of ethical and moral considerations in the scientists' work (Sadler et al. 2004).

However, in the perspective of an effective integration of Science and Technology as envisaged here, contents should be established, otherwise they would not be immune to disputes and coherence flaws. A corollary to this assumption is that measurable quantities are essentially the *key ideas* (see below) needed for reconstructing the content since in this way it is possible to guide the students to connect these quantities with natural phenomena which are valuable and relevant to investigate.

The corollary of measurability leads to the other two interlinked aspects of NOS that we consider important for the integration of Science and Technology: laboratory experiments and modelling. In this case we will shape our position on the work by Vicentini (2006; Danusso 2010). In both aspects, the key role is again played by scientists' choices, this time on a larger scale. S/he deliberately chooses what natural event to study and investigate: if the event is complex, after a first qualitative observation, quantitative parameters necessary for a mathematical description and interpretation of the phenomenon are selected. Such choice can be guided by theoretical considerations or attempts are made in order to achieve the necessary level of reliability of results obtained. A schema of this process is shown in Fig. 1.

We stress here the fact that such choice discriminates what is accessory to the phenomenon, and consequently negligible, and what is not: from such choice, a laboratory experiment will be designed and carried out to collect data to be analysed in order to construct a *scientific model* of the investigated phenomenon. Scientific models can be inserted into a wider schema (theory) useful to describe, interpret and predict different phenomena. More specifically, models are developed to respond to questions as: "how the phenomenon is manifested?", "how can it be reproduced and interpreted?". A relevant role in the process of integration of Science and Technology will be played by model's components and functions (Bunge 1973;

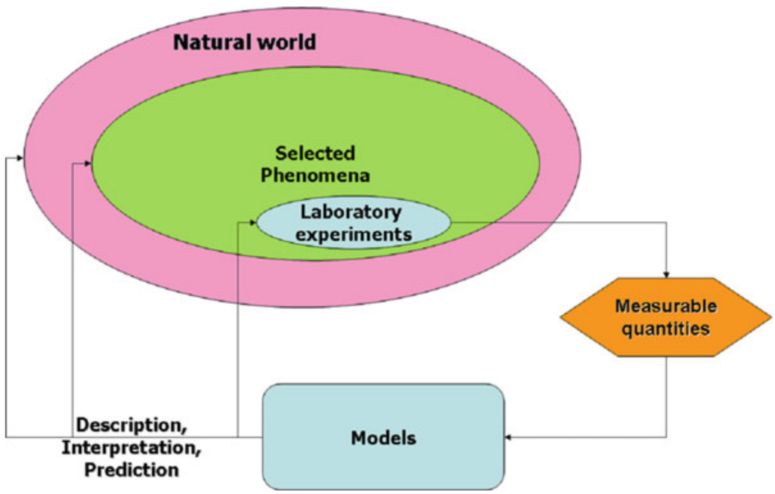

Fig. 1 Schema of the discussed NOS aspects for the generation of reliable knowledge (Adapted from Vicentini 2006)

Hestenes 1992): the components are the ensemble of the chosen measurable entities and of the law statements, validated by experiments, that relate them; the functions are basically the prediction and explanation of the observed phenomena.

For many readers, it is not difficult at this point of our discussion to envisage how the reconstruction of the content in terms of basic measurable quantities, which are the building blocks of the scientific knowledge, could play a central role in the integration of Science and Technology. However, we still need to specify how these aspects of NOS interact with specific features of the Nature of Technology (NOT) to give rise to a meaningful integration of Science and Technology. In the next section we will build on a new conceptualization of NOT in order to define the most relevant aspects for this integration.

4 The Nature of Technology: Some Uncharted Aspects

Previous review studies (e.g., DiGironimo 2010) show that consensus about important aspects of Nature of Technology (NOT) is yet to be reached. For instance, a definition of Technology can be found in every dictionary and the interesting issue is that each dictionary nearly gives a *different* definition.[11]

Basically, Technology can be knowledge, applied science, technique (or set of techniques), practices and art, or a "distinctive human achievement" (Gilbert 1992, p. 564). Also the Project 2061, in its *"Science for All Americans"* on-line document,[12] is rather scanty in giving any precise definition of Technology suggesting that it is a body of techniques that grew over the centuries establishing a unique and privileged relationship with Science to solve practical problems and enlarging the body of scientific knowledge. The Project 2061 document clearly puts into the front the relationship between Science and Technology but does not explain why such relationships should exist. While important to build integration between them, this relationship should be better clarified starting from a sounder definition of what is Technology.

Our position is built on the basic structural principles described by Arthur (2009): every technological object or device can be seen in a broader sense as a system with a given finality and built on several components (combination); every component is a technological object itself, even the most elementary part (recursivity); every technological object internally exploits a physical principle strictly related to a natural phenomenon (harnessing). The combinatory structure of technologies is depicted in

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[11] For instance, from the Cambridge Dictionary:

> science is the knowledge obtained from the systematic study of the structure and behavior of the physical world, especially by observing, measuring and experimenting, and the development of theories to describe the results of these activities; technology is the study and knowledge of the practical, especially industrial, use of scientific discoveries.

[12] On-line http://www.project2061.org/publications/sfaa/online/chap3.htm accessed September, 19th 2011.

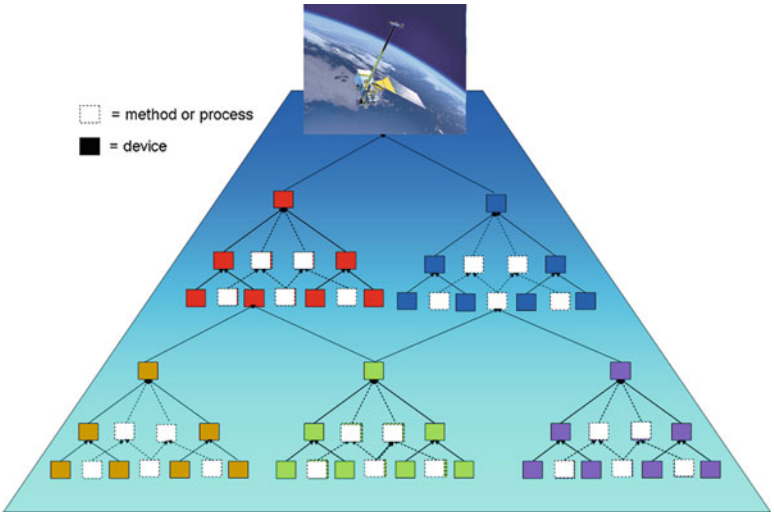

Fig. 2 A technological object seen as recursive combination of several technological components

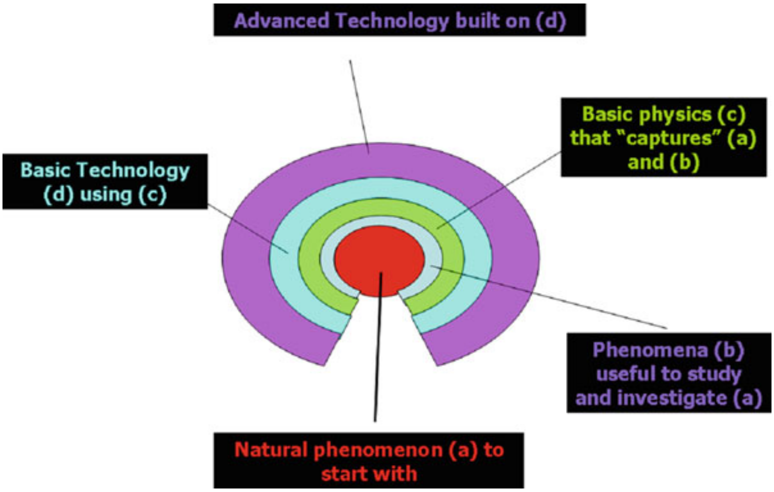

Fig. 3 Progressive harnessing of a natural phenomenon to be exploited by a technological object

the schema in Fig. 2. The process of harnessing and exploiting of natural phenomena is represented in Fig. 3.

Figure 2 shows that a technological object (for instance, a geostationary satellite) is the result of a complex tree-like structure in which technological processes and devices are suitably combined together into finite lower-level technological objects/process. These, in turn, are the result of the combination of other lower-level objects and so forth. Figure 3 shows how a single lower-level component of the tree-like structure of Fig. 2 is built. At the very heart of every technological object or device there is a single natural phenomenon (or a set of phenomena). This is easily recognizable from examples in the field of real-time measurements (Thornton and Sokoloff 1998; Sassi 2005; Sokoloff et al. 2007): a temperature probe uses a thermistor, i.e., a resistor whose resistance decreases nonlinearly with increasing temperature; a version of the force sensor is based on the Hall Effect; the motion sensor uses ultrasound waves echo. The phenomenon can be studied and interpreted using empirical laws and mathematical models. These abstract representations allow to reconstruct, in a controlled setting, the conditions for the phenomenon to happen in order to build a technological object or outline a technological process. Now the harnessing is complete and lower-level components will then be used to build higher-level components in the tree-like combination depicted in Fig. 2. More complex examples are reported by Arthur (2009).[13]

The adopted view warrants reliability to a sound Science and Technology relationships, given as an inevitable matter of fact in the Project 2061 document. Conversely, this view also warrants the role of Technology in SL: Technology builds on Science to discover and harness new useful phenomena while Science is based on Technology because of instruments, methods and experiments useful to investigate and reliably describe and interpret these phenomena.[14]

The adopted view also clarifies the role of another important aspect of NOT, i.e. technological design. It is the mechanism to build new technological objects by recombining and adapting existing ones. Design therefore is at the basis of the evolution of Technology, triggered by the quest for suitable solutions to a given aim using a repertoire of skills and resources which successful professionals manage and increase with time.[15] This view justifies the research findings (Sect. 2) according to which design activities can be considered pedagogically valuable to foster students'

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[13] This view is not in contrast with historical progression of Technology: some phenomena can be evident (e.g. the fire when rubbing small wood pieces), others can be much hidden and need more effort to be harnessed in a specific technological device (e.g. quantum effects). As pointed out by Arthur (2009):

> Science is indispensable to discover the most hidden phenomena, to create technologies that exploit them; moreover, it furnishes the conceptual instruments to observe these phenomena, the necessary knowledge to elaborate them, the theories to explain them and predict their behaviour, and often the methods to harness and exploit them.

[14] Another reason for which Technology cannot be simply viewed as applied science is the fact that most of the technological objects are very "far" from the original phenomenon on which each of their components has been built on. While taking advantages of the progresses of Science in describing further phenomena useful to capture the original phenomenon, these advanced technological objects have mainly built on existing ones exploiting the recombination mechanism at the basis of the evolution of Technology.

[15] In this view, to design means basically choosing solutions that must take into account available technological components as well as economics constraints. As scholars have suggested this makes creative problem solving an essential feature of design (e.g. Williams et al. 2008). As the design process, creative problem solving features: formulation of a problem, identification of goals and evidences related to the problem, evaluation of different possibilities, choice of the solution, test-

creative approaches to scientific and technological contents and engage them in authentic practices (see also, e.g., Benenson 2001; Stein et al. 2003).

Finally, because the scientific endeavour tends, since its birth (Galilei 1623), towards a given aim – i.e., the acquisition of reliable knowledge of natural phenomena (see Sect. 3) – a parallel between technological design and scientific modelling can be set up: as design allows to draw new technological objects from pre-existing ones, the modelling process allows scientists to build on seemingly independent components (variables and their relationships) to construct the description and interpretation of phenomena. *This parallel demands a renewed meaning to the integration of Science and Technology from the educational viewpoint: not a simple inclusion of activities from one field to the other but a completely new way of dealing with contents and methods to be used in the teaching/learning activities.*

Specifically, the idea of identifying the root of each technological object in a natural phenomenon is the conceptual pillar of the Science and Technology integration proposed in this paper: given a technological object or device, it should be first de-constituted of its components and the basic phenomena which it harnesses have to be identified; then, key ideas are identified and measurable quantities are related to these phenomena. In this way, it is possible to identify a Science and Technology common core, which is the object of the disciplines' integration.

However, to systematically derive this common core, an educational framework in which Technology and Science contents are *reconstructed* is needed. This process will be detailed in the next section.

5 A Framework for Integrating Science and Technology from the Content Knowledge Viewpoint

In Sects. 3 and 4, we inferred from the reviewed literature the basic need for an effective Science and Technology integration, namely, to *reconstruct* Science and Technology contents for educational purposes. This is not a matter of choosing an existing Science or Technology content that can be addressed focusing attention alternatively, according to the most up-to-date educational trends, to the Scientific or the Technology knowledge. Most of textbooks do so and they basically fail to give an informed idea of the relationship between Science and Technology (Gardner 1999).

As already pointed out in the introductory part of this article, some issues about the Science and Technology relationships have not been completely solved. In all these approaches, the close relationships between Science and Technology is acknowledged because these are already embedded in the complexity of modern western society and almost given for granted without any theoretical justification. More specifically, the contents addressed in these approaches are basically those addressed in traditional curricula and even approaches purposefully developed to

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ing and evaluation. Skills required for students to engage successfully in this process are: criticism, system analysis, divergent and lateral thinking.

struggle against the "*tyranny of school science*" (Bencze 2001) lack of a suitable attention to what kind of contents should be addressed.[16]

Basically, our view of integration emerges from the *elementarization* of a given broad *theme* in terms of two NOS and NOT content-related aspects that we have discussed in the previous two sections. Examples of such themes are, for instance: sensors; audio amplifiers; rockets; radio transmitters and receivers; circuits for the control of train traffic (see also Barak and Pearlman-Avnion 1999; Bencze 2001; Gardner 1999). We will give more details about the process of elementarization in Sects. 5.1 and 5.2. Here, we want to stress that the identified theme should feature a scientific content-related *component* and a technology-related *component*. These components are characterized respectively by:

1. Key ideas at the basis of a Science content
2. A natural phenomenon at the basis of a given Technology

Usual Science and Technology integrated teaching emphasizes alternatively one of these components (e.g., Barak and Pearlman-Avnion 1999; Geraedts et al. 2006). In our approach, on the contrary, first both components should be *reconstructed* for didactical purposes: the scientific part should be elementerized so to identify key ideas at its basis; similarly, the technology component should be elementerized so to identify the technological process or device to which it refers and then the natural phenomenon that this technology harnesses should be identified. At this point one can integrate the enucleated key ideas and natural phenomena in form of a single common core and proceed through the teaching using the authentic practices of scientific modelling and technological design to fulfil the intended learning outcomes. We will provide two working examples of our approach in Sect. 6.

The *reconstruction* dimension, also called in literature didactical transposition, has often informed design frameworks as those developed by the Leeds or Lyon groups (Psillos and Kariotouglou, this volume). However, due to our focus on the conceptual structure of content knowledge, we chose the Educational Reconstruction (ER) model (Kattmann et al. 1995) as suitable framework to carry out the identification of scientific key ideas and of natural phenomena which are harnessed by a technological device or process. After a very brief description of the framework (more details are provided in the introductory chapter), we will discuss in depth why this framework could usefully guide the process of Science and Technology integration.

5.1 The ER Model

The importance of the *reconstruction* of science content for educational purposes is well established in the German tradition of "*Bildung*" and "*Didaktik*", concepts whose English translation is difficult. The English term "formation" does not

[16] Obviously, we do not assert that these efforts fail to adhere to their own view of framing the integration of Science and Technology but only that they reflect a view of integration that resembles a rather simplicistic way of putting together Science and Technology contents.

completely convey the meaning of "Bildung", i.e. the psychological, educational and cultural development of the learner as a whole person. Similarly, "Didaktik" has a much wider meaning than the English "didactics", which essentially refers to issues of educational practice. "Didaktik" is linked to "Bildung". In German, it means transforming disciplinary or cultural knowledge into a knowledge form suitable for teaching and aimed at contributing to learner formation ("Bildung"). The teaching process is viewed as being composed of two closely interrelated phases: "*elementarization*", where key elementary ideas of a specific content are identified; and "*construction of the content structure for instruction*". Major reference of Educational Reconstruction is the "Didaktische Analyse" approach (Klafki 1969, 1995).

Epistemologically, the ER refers to constructivist viewpoints (Duit 2007): learning as a process of building one's own science knowledge starting from previous ideas, experiences, conceptions and knowledge (Driver and Easley 1978); science as a social construction (Abd-El-Khalick and Lederman 2000).

Three interrelated components are featured in the ER (Duit et al. 2005):

1. The first component refers to clarification/identification of scientific ideas in the specific content from an educational viewpoint and to their educational significance ("elementarization" of the content). Here, the focus is on "key ideas", i.e., the basic concepts and phenomena that might help to transform the given content into one suitable for teaching.[17]
2. The second component refers to the analysis of students' and teachers' perspectives, alternative/naïve conceptions, affective variables, etc. that are relevant for the particular instruction.
3. The third component refers to the design of educational materials and activities at the core of the teaching-learning sequence. Here content reconstruction materializes in the design of activities to help students understand the scientific contents.

5.2 Use of the ER Model to Integrate Science and Technology

The ER framework refines the rationale for designing teaching/learning aimed at effectively integrating Science and Technology (Fig. 4).

The starting point is the common Science and Technology theme. Then, the ER model allows identifying the key ideas underlying the scientific component of these contents (through the analysis of textbooks, epistemological studies, historical review, …). It is therefore possible to select measurable quantities and exemplar

[17] For instance, a key idea to start the teaching of electric circuits may be the concept of potential difference. Similarly, a key idea for the teaching of mechanical waves may be to address the fact that a small portion of a string perturbed by a transversal train-pulse, oscillates vertically around its equilibrium position.

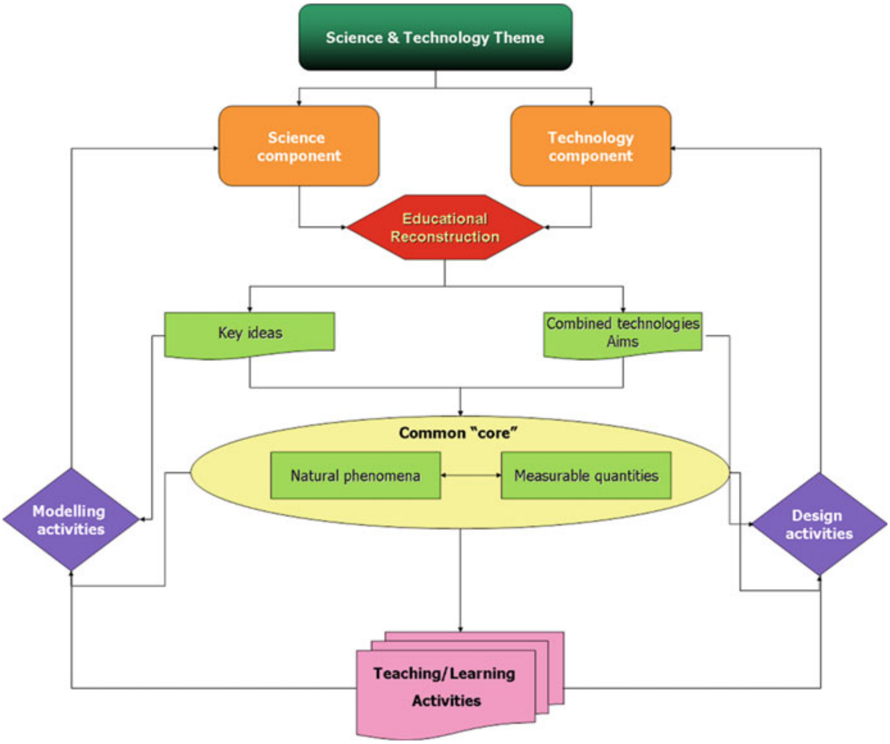

Fig. 4 Process of educational reconstruction to integrate Science and Technology

experiments useful to construct simple mathematical models. The process should be guided by the question of what could be considered as principal or secondary for the content to be reconstructed. For instance, if the aim is to construct a simple energetic model of the bouncing of ball on a floor, one may measure the subsequent maximum heights and concentrate the analysis on the floor's material and on the sound emitted during the hit, disregarding the effects of the air friction.

The same route can be followed to reduce the technological component into its basic technologies and to identify the physics of the natural phenomena harnessed. The two routes should converge into *common* enucleated core made up of experiments and measurable quantities to study and describe phenomenology which is relevant to the chosen contents. The process may also take advantage of scientific modelling and technological design activities carried out to exemplify the role of the measurable quantities in the scientific and technological components interplay.

Although for the theoretical viewpoint here discussed the reconstruction of the content in terms of key ideas, relevant natural phenomena, modelling and design processes as essential, a privileged role is not assigned to the ER model. The same outcomes, from the pedagogical viewpoint, could *in principle* be obtained through different approaches or frameworks.

However, the ER model provides a detailed coherent framework, widely validated and used in different contexts, from teacher education (van Dijk and Kattmann 2007) to informal learning in out-of schools experiences (Laherto 2013). It explicitly aims at the reconstruction of contents starting from the structure of the content itself, a dimension usually not emphasized in other research-based framework useful to design teaching interventions (Design-Based Research Collective 2003; Lijnse 1998). Given the relevant role of content structure in the adopted views of NOS and NOT, the ER model has been the most suitable choice.

6 Contextualizing the Science and Technology Integration in Teaching-Learning Sequences

In this section we will briefly discuss a possible implementation of the ER model for a successful Science and Technology integration in a TLS. As argued in the introductory paper (Psillos and Kariotoglou, this volume), the development of a TLS may lead to valuable research results in terms of understanding learning processes or validating theoretical models, and students' learning outcomes. We used the TLS dimension to investigate: (1) the validity of the theoretical framework adopted for the integration of Science and Technology; (2) the effectiveness of designed activities for students' learning of Science and Technology related concepts and views. In this section we focus on how a TLS may be designed using the framework. In the case study we will focus on the effectiveness of the TLS.

Basically, the first choice concerns a suitable *theme* which features both Science and Technology components. A theme should be wide enough to include Science and Technology considerations, but not too extended to be dispersive. A specific need or aim can be associated to this theme to emphasize the aim of the Technological component. This first step does not differ from previous proposals (e.g. Beven and Raudebaugh 2004).

At the second step, our approach diverges from previous ones: the chosen content should be reconstructed following the indication of the ER model. As pointed out in the previous paragraph, such reconstruction includes: identification of the key scientific ideas at the base of the Science component to be reconstructed; identification of the phenomenon at the basis of the technology component; investigation of this phenomenon and of any related relevant phenomenology; addressing of common alternative conceptions about the scientific contents relevant for the phenomenon; construction of suitable models of the observed phenomenology and design of the solution to meet the original need; evaluation of such solution and, if needed, investigation of further significant phenomenology to re-design the solution.

From what pointed out above, the choice of the specific theme to address, with its Science and Technology component, is essential. In our opinion, some content areas are more appropriate than others to foster a better integration process.

Materials science is one of these areas, together with others like biotechnologies, computer science and neurological imaging. Materials science is particularly appropriate since it is intrinsically interdisciplinary (covering aspects of physics, chemistry, engineering, etc), has a relevant technology component, and possesses a high potential impact on society (new materials and their applications are likely to figure strongly in any reasonable scenario of the technological future).[18] Moreover, learning about "materials" is being introduced in current science education reforms as a goal in itself (Cajas 2001, p. 723).

A relevant field of the Materials Science area to show the strict science/technology interaction is that of the macroscopic properties of materials. Students' alternative ideas and naïve reasoning related to this field have been previously addressed in Science Education research, especially those concerning the particulate nature of matter (Driver et al. 1985; Lee et al. 1993). Moreover, didactic proposals (Russell et al. 1991; Roth 1998) have addressed aims as: to distinguish between an object' s properties (e.g., geometry, colour) and the properties of the material(s) that constitute the object (physical, chemical, …); to improve students' understanding of the functional role of such properties for choosing suitable materials in order to complete a given design. One example to illustrate how contents related to properties of materials could be reconstructed by means of the ER analysis is extensively reported in a following chapter of this book, using optical properties of materials as main theme. Another brief example is reported in the Appendix.

7 Conclusions and Implications

In this paper we have tried to answer two research questions: What contents should be taught in approaches aimed at implementing an integration between Science and Technology? How should these contents be treated to achieve an effective integration? To this aim, we have proposed an integration of Science and Technology from the content knowledge perspective, building on relevant aspects of NOS and NOT. These aspects can be resumed as follows:

- Science knowledge, constituted by theories and models constantly validated through agreement with experience, has as main goal the analysis of natural phenomena purposefully investigated through carefully designed experiments and

[18] Materials Science addresses different but connected content areas. One is aimed at developing new materials for technological uses. This kind of research requires a basic knowledge of physics and chemistry, in particular about the macroscopic properties (known and desired) of materials (mainly solids) and the microscopic models explaining the known properties at the basis of studies toward the desired ones. The development of new organic materials is also being pursed in genetic engineering, bioengineering and biotechnology. In this case basic knowledge of biology and chemistry is needed, specifically concerning the macroscopic properties of biological systems and the microscopic models appropriate for the desired properties. In all these disciplines there is a link to technological applications and a common basic knowledge: the scientific description of macroscopic properties of materials and the microscopic models used to explain them. There are differences at the macroscopic and the microscopic level: for inorganic materials the properties are mainly physical and chemical; the models use atoms and subatomic particles as components. For organic materials biology comes in and the models use biological macromolecules or genes as components.

described, interpreted and predicted by theories and models, whose components are measurable quantities and their relationships;
- Technological knowledge has as main goal to solve specific problems through assembling practices and components and recombining existing technologies improved in small steps done by the selection of better solutions to design problems. Every technological object or device is a system characterized by a given aim and is built on several components, each itself is a technological object, which harnesses and/or exploits a natural phenomenon; the basic mechanism that allows to re-combine existing technological objects to obtain a new one is the technological design.

These aspects form the theoretical basis for the proposed integration of Science and Technology, since both at their very core rely respectively on investigating and exploiting natural phenomena. Therefore, to ensure this integration, the scientific and technological contents, which in the school curricula are separately finalized for the bodies of knowledge of Science and Technology, should be first elementerized and reconstructed until their core phenomenon is disclosed.

The ER model has been adopted to frame this process having in mind the broader aim of developing TLSs which effectively integrate Science and Technology. To answer specifically to the first research question, the model is applied in two examples (see Appendix) to show how specific themes can be elementerized. This implies to enucleate key ideas, to experimentally investigate relevant phenomenology and to describe it with suitable models. Some suggestions for design tasks to enrich the reconstruction of the technological contents are also discussed.

The following potentialities of the proposed approach can be highlighted from the SL perspective.

First, the approach overcomes some difficulties in STS, STSE and SSI instruction in dealing with Technology, as essential component of SL. In particular, the term “technology object or device” is used instead of technological “applications”, to stress the fact that every technological object is a combination of existing ones. In this view, the *human need* that Technology satisfies is important as well as the *phenomenon* and the *physics* that it exploits. As a consequence, the “technology as applied science” viewpoint fades away: namely, both Science and Technology rely on a common, educationally relevant to help students *become* and *act as* informed citizens.

Second, the envisaged reconstruction process, by identifying a common core as a part of Science or of Technology, addresses the issue of the quantitative integration of scientific and technological contents in previous approaches. In the teaching practice, it is then possible to focus mainly on the relationships (moral, economical, political, …) between the proposed themes and societal issues, diminishing possible resistances in introducing them in the school practice (Gayford 2002; Sadler et al. 2006) and helping students use meaningfully the acquired knowledge to decide on these issues (Sadler and Zeidler 2005b).

Third, the inclusion of design tasks into science teaching is strongly justified since technological design is an essential component of the proposed approach, with an analogous role to scientific modelling. Design tasks are hence not fashionable ways to improve science teaching, but tools to show recombination of existing technologies to obtain new ones.

A final consideration concerns some previously debated implications for Science and Technology teachers (Carlsen 1998; Barak and Pearlman-Avnion 1999). In particular, the proposed approach may help overcome usual difficulties teachers found in Science and Technology integrated proposals (reported by Barak and Pearlman-Avnion 1999; and by Geraedts et al. 2006). Actually, it does not add the two school subjects and does not demand teachers to look for difficult balance of contents. On the contrary, it fosters the teaching of common core contents and elicits some profound aspects of the nature of *each* of the two disciplines. Moreover, teachers are not asked to leave out traditional contents; if suitably reconstructed, they can be used as starting point to identify a Science and Technology common core. The Properties of Materials topics (Sect. 6) are further examples to introduce students to key concepts in Science and Technology.

Therefore the approach discussed in this paper can be valuable from the educational viewpoint provided that science and technology teachers become eager to address epistemological roots of and to bridge the existing gaps between the two subjects.[19] It is our convincement that when teachers become aware of the epistemological commonalities between Science and Technology, they, at least, are able to open up their school curricula "disciplinary boxes" (Carlsen 1998).

Appendix: Outline of an Example Which Uses Properties of Materials as Suitable Field to Integrate Science and Technology

Electrical Properties of Materials

Their educational relevance comes from the very many applications of electrical circuits in everyday life. They include electrical conductivity, dielectric strength and temperature coefficient of resistivity. A possible starting point is the study of the safety and comfort of cars (Science and Technology connected part) with the specific aim of reducing effects of mechanical vibrations (emphasized technological aim). The scientific component at its very core refers to the concept of potential difference at the ends of materials and how it depends on the system which the materials are part of. The technological component consists in the electronic device present in every modern car that controls and monitors the external vibrations.

[19] For instance, in Italian secondary schools, Physics teachers in Lyceums usually focus more on conceptual knowledge, while Electronics teachers in technical/vocational schools generally place more importance on laboratory practice.

Some key ideas suitable to reconstruct the potential difference concept are the density of charge or the energy and work per unit charge. The core phenomenon at the basis of the electronic device is piezoelectricity, an effect that allows the conversion of a mechanical stress into an electric voltage.

Once we have reached the common core content, it is possible to carry out investigations to measure potential differences across conductors or piezoelectric crystals, using electric cigarette lighters or portable sparkers. Finally, the teaching may address how to interpret and predict variations of potential difference at the ends of conductor materials as well as the design of a feedback device to control cars' vibrations focusing on the behaviour of materials exhibiting the piezoelectric effect.

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