australasian journal of
TECHNOLOGY EDUCATION

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Publisher: The Technology, Environmental, Mathematics and Science (TEMS) Education Research Centre, which is part of the Faculty of Education, The University of Waikato, publishes the journal.

Contact details: The Editor, AJTE, pj.williams@waikato.ac.nz

Cover Design: Roger Joyce

ISSN: 2382-2007

australasian journal of
TECHNOLOGY EDUCATION

Volume 1, 2014

australasian journal of
TECHNOLOGY EDUCATION

Volume 1, 2014

Exploring the Relationship between Science and Technology in the Curriculum

Abbad Almutairi, John Everatt, Paul Snape, & Wendy Fox-Turnbull

Abstract

The position of science and technology in the curriculum has been debated, particularly from the perspective of their relationship. Some consider science and technology to be independent subjects while others believe that technology is applied science. This has led to a lack of a general consensus about the way science and technology should be taught, whether as independent or integrated subjects in the classroom. The general purpose of the paper is to provide a discussion about this issue by addressing the nature of science, the nature of technology and the nature of the relationship between the two. Based on the discussion, a model of the relationship between science and technology was developed as a pedagogical approach, which can be used as a guide to teaching science and technology separately, taking into account their interdependence and the way they can combine to produce solutions for society and the environment.

Key words: curriculum, science, technology, a pedagogical model

Introduction

Science and Technology have been included in international curricula as major subjects that play a role with other subjects in providing students with essential theoretical and practical skills (Jones, 2009). The relationship between science and technology has long been debated by scientists, technologists, science teachers, technology teachers, politicians and members of the community in general who have not been able to reach general agreement on a framework that determines that relationship. A suitable framework might be used as a guide for science and technology teachers to teach both subjects either independently or interdependently. In France, for example, Lebeaume (2011) stated, "Technology education has a long history in the dynamics of design and implementation of compulsory school subjects: there have been numerous tensions about its specific contents and its relationship with scientific school disciplines, especially with physics-chemistry" (p. 77).

Likewise, in the UK, despite school politics emphasizing the difference between science and technology without considering the similarities between them, the Thatcher Government encouraged and financially supported the initiative of a Technical and Vocational Education Initiative to integrate science and technology as a combined curriculum (McCormick & Banks, 2006).

Albe and Bouras (2008) considered technology as being an application of or subservient to science. Also, attempts to integrate technology with science have emphasized technology as an applied science and have represented a very limited view of technology that has restricted the learning in both subjects (Jones, 2007) but their relationship within education can be beneficially explored to enhance learning in both areas (Compton, 2004a).

The issue of considering technology as applied science has created much debate about the relationship between science and technology in the curricula (Kipperman, 2006). For Gravemeijer and Baartman (2011), the reason for the debate is that there is no clear agreement among scientists and technologists on the definitions of science or technology, or the relationship between science and technology. Thus, it has been quite common for people "to talk about 'science and technology' as if it was one thing with a double-barreled name" (Sparkes, 1993, p. 25). It is time to re-evaluate this relationship. Cajas and Gallagher (2011) indicated that the cluster of articles published in the Journal of Research in Science Teaching (2001, 38(7)) analyzed the relationship between science and technology. The summary that emerges from these academic articles is that there is a complex relationship between science and technology and "such complexity should be reflected in the school curriculum" (p. 713). Cajas and Gallagher (2011) called for a re-evaluation and re-study of this relationship. de Vries (2001) explained that the study of the complex relationship between science and technology can be pursued through tracking the history of industrial research laboratories and provides a good opportunity for understanding why and where such complexity exists. It is essential to reveal these points of view about this issue, to examine them in order to determine the relationship between science and technology and to deliver this message to all who are interested in this field - especially science and technology teachers - in order to improve their understanding about this contentious issue.

Many articles have been written about the relationship between science and technology but the literature indicates that no framework has been developed that clearly articulates this relationship (Compton, 2004a; Gravemeijer & Baartman, 2011; Jones, 2007). "Attempts to distinguish between the two based on epistemological criteria have been less than convincing" (Custer, 1995, p. 226).

The major thrust of this article is to present an image of the relationship between science and technology and to have a robust understanding of this relationship in the curriculum. It is hoped that this will assist to develop a pedagogical model which represents the relationship between science and technology. The article discusses this relationship through shedding light on the following points: firstly the nature of science; secondly the nature of technology; thirdly the nature of the relationship between science and technology; and fourthly suggesting a pedagogical model of the relationship between science and technology in the curriculum.

Nature of Science

The nature of science is a generic concept that contains various components or sub-concepts that help people understand what science is. Hodson (2012) identified three major areas of scientific literacy: learning science, learning about science, and doing science. He declared that the second component, learning about science, includes the factors required to learn about science such as language, theoretical views, norms and traditions of science: these factors represent the nature of science. McComas and Almazroa (1998) provided a comprehensive explanation of the nature of science that was directed at science teachers to enable their students to gain understanding of this concept. They explained that it is about mixed aspects of diverse social studies of science: "The history, sociology and philosophy of science with research from the cognitive science into a rich and useful description of what science is and how it functions" (p. 511). Based on Hodson's suggestion, and the explanation by McComas and Almazroa (1998)of the nature of science, we propose that these aspects shape the knowledge that educators and their students should first hold in order to learn about science.

Understanding the nature of and grounds for knowledge itself (epistemic cognition) is a prerequisite for any understanding of the nature of science (and technology likewise) (France & Gilbert, 2005). Moshman (1998) defined epistemic cognition as "an aspect of metacognitive understanding involving knowledge about the nature and limits of knowledge, including knowledge about the justifiability of various cognitive process and actions" (p. 964). Based on this definition, we can increase our understanding of the nature of either science or technology that can be determined through knowledge about their processes and actions. He indicated that a variety of theories and research programs have focused on the development of epistemic cognition. Children, adolescents and adults were involved in the research to understand the stages of the development of ideas about the nature of knowledge across these ages. He concluded that there are three development stages: objectivist, subjectivist, and rationalist.

The objectivist stage "construes knowledge as absolute and unproblematic. Justification, if considered at all, is simply a matter of appealing to direct observation or to the pronouncements of an authority." (Moshman, 1998, p. 694). People in this stage accept and have an absolute belief in the scientific knowledge that is pronounced by scientists. This scientific knowledge includes laws and theories used to explain and describe everyday events, problems and phenomena (Naughton, 1993). Scientific knowledge in general is a systematic and methodological method used by scientists to discover reality and is the key concept that represents the nature of science. Two terms will frequently be used to discuss the nature of science: "scientific knowledge / and science. There is no difference between them and they reflect the concept of 'Science'" (p. ?).

The subjectivist stage is where "Knowledge is deemed to be uncertain, ambiguous, idiosyncratic, contextual, and/or subjective; justification in any strong or general sense is considered impossible" (Moshman, 1998, p. 694). France and Gilbert (2005) attributed this to a lack of understanding scientific knowledge that leads people to reject scientific arguments and all other consequences resulting from it.

The rationalist stage is where people recognize that "there are justifiable norms of inquiry such that, in some cases, some beliefs reasonably may be deemed to be better justified than others" (p. 295) In this stage, people have the scientific norms that help them accept the scientific facts as truthful or entirely false.

France and Gilbert (2005) found the nearest approach to an analysis of the epistemic status of the nature of science in public was the review (Koulaidis & Ogborn, 1995) when they reviewed science teachers' views on the conduct of scientific enquiries and the status of the outcomes. They identified four fundamental views: *inductivism; hypothetic-deductivism; contexualism; and relativism* .

Inductivism allows people to consider science as a process to collect final scientific facts derived from regular observations of general laws.

Hypothetic-deductivism: people can propose hypotheses about a particular phenomenon, after they expose these hypotheses to experimental research to approve correct ones and to eliminate others.

Contexualism: specific scientific theories are judged in terms of the notions of successful scientific enquiry prevailing at that time.

Relativism: there are no specific characteristics of scientific knowledge to be used as a standard to compare it with other forms of knowledge if needed. This point of view is supported by Pitt (2001) who indicated that there has been no general agreement as to the criteria for scientific knowledge.

Compton (2004a) identified three key criteria that can be used to differentiate between science and technology: the purpose of science, the ontological stance and the epistemological aspect. These criteria can be logically used to discuss the nature of science and the nature of technology if the first criterion is changed to the purpose of technology and the second is thought of in relation to technology rather than science. These criteria are key factors in theory and practice of science and technology and are fundamental in discussing the relationship between the two disciplines.

First, Compton suggested the purpose of science is to *explain* the natural events through reiterated observations and control. Similarly, Pitt (2001) stated that the ultimate aim of scientific enquiry is explanation in order to understand the way the world occurs to us.

Secondly, Compton (2004a) also suggested that the ontological stance of science plays a prominent role in helping us to understand the nature of science. This stance reflects a contemporary view of those who consider science as a "critical realism" and claims that things have existed in the world since ancient history and they still exist as they are! Scientists adhere to the so-called 'correspondence theory of truth' to discover these things (Lepoze & Potter, 2001). The ontological stance attempts to inquire into the form and nature of reality and what can be known about it including "how objects really are" and "how do they really work?" (Guba & Lincoln, 1994, p. 29). The role of scientists, in this case, is to scientifically enquire about reality to generate a clear explanation of it. The explanation is followed by regular observations to introduce reliable facts.

Finally, the epistemological aspect is the third criterion that is used to differentiate between science and technology. This aspect represents the nature of the relationship between people and reality (Guba & Lincoln, 1994). Guba and Lincoln asserted that the person who works to discover the reality must be value-free to reach accurate and realistic results (knowledge) of his or her research. Developing knowledge is a substantial aim of science (de Vries, 2012): this knowledge “must adhere to logical reasoning and be internally coherent within the dominant paradigm…. It must withstand peer review in order to be represented as ‘truth’” (Compton, 2004a, p. 2). The epistemological aspect of science is how knowledge is scientifically acquired and how it is transmitted to recipients. Scientific knowledge in science attempts to make claims to a ‘truth’ that represents the epistemological basis of science (France & Compton, 2006).

As educators, we must not only aim to help students to gain knowledge of how things in the natural world act (*ideas of science*) but also how this knowledge is structured and developed (*ideas about science*) (Léna, 2011, p. 2).

Nature of Technology

To understand the nature of technology we need, as in the case of the nature of science, to understand the purpose, the ontological stance, and the epistemological stance of technology.

The purpose of technology can be understood through the definitions of technology given by some science and technology experts. Naughton (1993) defined technology as “the application of scientific and other knowledge to practical tasks by organizations that involve people and machines” (p. 9). He said a general purpose of this definition is to solve the problem or to make something. France and Compton (2006) referred to technology “as a form of human activity that exists through the purposeful intervention of technology; the intervention is specifically designed to meet needs or realise opportunities as they are perceived to be within specific time, space and place locations” (p. 4). Thus, France and Compton (2006)believed that technology as a human activity allowed the production of innovative solutions and provided the means to extend human capability to create useful things required to solve life's problems. This suggested purpose of technology was also identified by Atkin (1998) when he explained that the purpose of technology was to create something that people wanted or that made their lives more productive.

The second factor that assists in understanding the nature of technology is the ontological stance of technology. Phenomenology is a philosophical stream that constructs a view of technology. de Vries and Dakers (2009) suggest the best known example of an early philosophy of technology is the philosophy introduced by Heidegger (1977). For Heidegger, the general existence of technology in society has led to the consideration of all things around us as resources that we use without appreciating the reality of the resources' contribution to environmental sustainability. For instance, the external beauty of the tree does not attract businessmen who work in the timber business: instead, they think of how many planks or pencils they can get from trees. The process has become evident in our perception of reality. This notion is supported by France and Compton (2012) who described technology as upholding ‘process ontology’. Process ontology allows the categorization and description of components of any product and the relationship between them that make up a process. From such an ontological point of view, France and Compton commented, “We are creators of the material world of technology in clear and tangible ways, but are also symbolic creators of the world as a whole” (p. 3). In addition, they argued that the role of technologists, in this case, was to interact with available resources to be improved and used to meet the needs of communities.

The epistemological basis of technology is a major factor used to determine the nature of technology. In the previous discussion about the nature of science, we understood that the scientific knowledge in science attempts to make claims to ‘truth’ and this knowledge represents the epistemological basis of science. In fact, knowledge in science is discovered and prepared by scientists to be used by technologists who use it to design and produce products for the use of mankind (Léna, 2011). Hence, using scientific knowledge in practice is an important point that helps to reveal the nature of technological technology. This transformation of scientific knowledge to technological knowledge creates a contentious question: Is technology just the application of science? This question will be discussed in the following section (The nature of the relationship between science and technology).

Technological knowledge is a major component in shaping the concept of technology and has a purpose different to that of scientific knowledge. According to Compton (2004a), the purpose of technological knowledge is not to make claims to 'truth' in the same manner as scientific knowledge does, technological knowledge attempts to understand the 'process of function'. Compton (2004a)also argued that technological knowledge is validated by success whereas the truth validates scientific knowledge. Wiggins (2012) provided other terms for technological knowledge; practical knowledge (knowing how); and scientific knowledge; propositional knowledge (knowing that). He stated that we may be unable to practice the practical knowledge without connecting it sometimes with the propositional knowledge. McCormick (1997) called these types of knowledge; conceptual knowledge, "knowing that"; and procedural knowledge, "knowing how". He argued that the "know that" is conceptual knowledge concerned with tracking facts to explore the relationship between items of knowledge; conceptual knowledge simply allows us to explain why things happen, while the "knowing how" is attributed to technology which simply means how to do it. Despite the different features of conceptual and procedural knowledge, they have an interrelationship that is seen by McCormick (1997) as crucial and effective in solving problems in science or mathematics.

France and Compton (2006) explained that the nature of technology, technological knowledge and technology practice work together to support the concept of 'Technological Literacy'. They indicated that the nature of technology provides an explanation of how technologies occur and how these technologies are influenced by historical, social and cultural dimensions. Technological knowledge provides an explanation of technological practice and technological outcomes. Compton (2004b) identified two categories of knowledge: tacit knowledge or implicit knowledge, and explicit or focal knowledge. Tacit knowledge is the knowledge which can be shared and articulated with others; "it is embedded in the subconscious" (p. 3). It consists of beliefs and values that shape our understanding of the world while the explicit knowledge is the knowledge that can be easily articulated and shared with others. Custer (1995) identified two types of technological knowledge: tacit and analytical. *Tacit knowledge* is beyond verbal expression and is processed by craftspeople who are highly skilled in technology. A*nalytical knowledge* is where the technological knowledge is processed through scientific knowledge and functional knowledge that offer mathematical solutions for the technological product under process. The body of the technological knowledge includes three components identified by McGinn (1990): knowing how to do, resources, and methods. The knowledge of how to do certain things by using specific material products or by transforming specific material objects is the first component. This component is about "knowing how to do". The second is the knowledge of the resources used in technological activity. This knowledge requires technologists to understand the nature of these resources and the properties of materials selected for any technological product. The third is the knowledge of methods used in reaching the anticipated outcomes of the technological activity.

Nature of the relationship between Science and Technology

The nature of the relationship between science and technology has been discussed and addressed by philosophers and experts in these fields. They attempt to distinguish between disciplines and to understand the relationship between them. A good comprehension of the relationship between science and technology is relevant for shaping appropriate concepts of each in both science education and technology education. This section discusses this issue by providing some perspectives derived from relevant literature.

The literature suggests that the argument about the relationship between science and technology focuses on two key issues. One is the issue of the distinction between the disciplines, and discusses similarities and differences. The other concerns whether technology is applied science.

The first issue relates to confusion among people whether science and technology are two distinct domains with their knowledge base or if they are same, doing the same job (Van Den and Van Keulen (2011). This has led many researchers to investigate this topic to identify the relationship between science and technology and thus to remove the ambiguity that caused that confusion. Brook (1994) metaphor of the two strands of DNA is the most appropriate metaphor found in the literature illustrating the relationship between science and technology. As a scientist, Brook thought the relationship between science and technology is parallel and connected knowledge that has existed over time; the domains can exist independently but cannot produce functional results until they are paired. In addition, he stated that science contributes to technology in at least six ways as:

1. New knowledge which serves as a direct source of ideas for new technological possibilities.
2. A source of tools and techniques for an efficient evaluation of feasibility of designs.
3. A research instrumentation such as laboratory techniques and analytical methods used in design and technological practices.
4. Practice of research is a source for improvement of new human abilities useful for technology.
5. Creation of social and environmental knowledge that has become important for technology in relation to its wider influence on environment and society.
6. A scientific knowledge base that offers more efficient strategies of practical research of new technologies.

Brook argues that the converse impact of technology on science appears in two ways: extending the agenda of science through providing new scientific inquiries after putting previous scientific discoveries into practice; and as a source of instrumentation and techniques required to process the scientific enquiry in a sufficient manner.

de Vries (2001) suggested that the history of industrial research laboratories provides a good opportunity for investigating the complex relationship between science and technology and he believes that a good understanding of this relationship is necessary to formulate the concept of science and technology education. He indicated three different interactions patterns of this relationship derived from the history of industrial research. Firstly, between 1900-1940 *science was an enabler for technology.* At this time, there was a narrow relationship between science and technology that existed in one direction when the laboratory developed new knowledge that supported the company product diversification. Secondly, between 1945-1975 *science was a forerunner of technology*: in a report entitled ‘Science, the endless frontier’ the scientific advisor to the President of USA reported that science is the basic source for technological progression in the industrial sector. In this period, the general goal of a research laboratory was to focus on fundamental research as a distinctive contribution to technological development. In this period there was a supposition that technology was an applied science. Thirdly, from 1970 to the present, *science has been a knowledge resource for technological developments.* In this period, a new science–technology interaction pattern occurred as a result of a number of economic and social changes that changed the policy of research in industrial laboratories. Gardner (1994) argues that this reflects the interactionist view that has united scientists and technologists as a team who work together and learn from each other. Gardner (1994)also identified four possible positions of science-technology relationship: science precedes technology, technology precedes science, technology and science engage in a two-way interaction, and science and technology are independent.

First, *science precedes technology*. This means that the technological knowledge grows out of the scientific knowledge or, as Gardner (1994) described it, technological fruits fall from scientific trees. This position continued during the second period of the relationship between science and technology identified above by de Vries (2001). In that period, technology was seen as applied science. This view imposed on teachers in general, and science teachers in particular, the task of teaching technology as an application of science. Secondly, *technology precedes science* (the materialist view) indicates that technology had existed historically prior to science and the ancient artifacts are enough evidence for that. Based on this view, Gardner argued that the historical and ontological argument (that technology precedes science) has had an educational influence on educators. In this case, educators choose students who have technical skills to perform scientific activities for the purpose of technological innovation. Thirdly, *technology and science engage in a two-way interaction* (the interactionist view). This position brings scientists and technologists into one arena of science and technology to exchange scientific and technological knowledge, and, between them, to produce useful solutions for their communities. This view will help to break down the boundaries between science and technology and will lead to design content that will assist teachers to teach them either together in the classroom or separately and yet keep the connection between their content. The last position that Gardner identified was that *science and technology are independent*, with different goals, methods and outcomes (the demarcationist view). This view considers science and technology as distinguishable fields that have different goals, methods and groups of people who have different skills and knowledge. Sparkes (1993) discussed the differences between science and technology: these are summarized in Table 1.

Table 1: Summary of the differences between science and technology

Criteria of differences	Science	Technology
Goals	To pursue knowledge and understanding for its own sake.	To create technological artifacts and systems to meet people's wants and needs.
Knowledge introduced	Scientific	Technological
Way of processing knowledge	Through experimentation and theory creation.	Through design, invention and production as implementation of theory in science.
Reductionism & holism	Breaking and isolation of materials to explain the phenomenon.	Integrating theory, ideas and data to for the design purpose.
Value judgment	Value-free	Value-laden
Conclusion & decision	Takes time to obtain more data if the current data is insufficient.	Product has a deadline and technologists can make a decision based on incomplete data.
Research	Search for new knowledge and understanding through controlled experiments.	Search for development of products by searching for the principles underlying better processes.

Source: Sparkes, 1993.

Contrary to the demarcationist view that stresses the differences between science and technology, McCormick and Banks (2006) assert that there are some obvious similarities between science and technology in terms of three dimensions: both offer hands-on learning; both claim to support problem-solving; and both attempt to encourage students to be involved in authentic learning by linking school activities to useful learning that students need in their daily life and the future needs of the work-place. Such a view has led some countries, such as the Netherlands, to consider technology and science as two mutually constitutive practices (Van Eijck & Claxton, 2008). In addition, such an understanding of the intimate relationship between science and technology influenced the developers of science and technology curricula. For instance, based on the discussion about the fundamental strands of learning science from kindergarten to Grade Eight, Van Den and Van Keulen (2011) categorized skills and attitudes that teachers need to teach primary science and technology into five categories:

1. Knowledge of important concepts and theories.
2. Knowledge of the nature of science and technology.
3. Knowledge and skills concerning inquiry and design.
4. Scientific attitudes (curiosity, respect for evidence, creativity, perseverance, critical and open mind).
5. Knowledge and skills with regard to teaching and learning science and technology (Pedagogical Content Knowledge).

However, these are general skills that teachers need to teach science and technology but there are also specific skills required in each subject that teachers need to be aware of. In order to teach science well, science teachers should acquire knowledge about science theories, knowledge about the nature of science, inquiry skills, skills in developing hypotheses about events, data gathering skills, observation skills, interpretation data skills, and pedagogical content knowledge skills. In terms of technology, teachers should acquire the following knowledge and skills: knowledge about technology theories, knowledge about the nature of technology, design skills, problem-solving skills, processing materials skills, tool and equipment using skills, and pedagogical content knowledge.

Similarly, in Arabic literature, Al-Khateeb (2000) asserts that science and technology are not one subject; they have different activities although these can be depend on each other. Al-Khateeb explains that it is difficult to discuss technology without some reference to science and vice versa. In his book, *Teaching Technology in Public Schools,* (Fath-Allah, 2006) declared that the differences between science and technology can be understood by looking at the goals and the outcomes of each discipline: the goal of science is to know why? and the outcome of science is to produce theories and laws: while the goal of technology is to know how? and the outcome of technology is to design and to make products.

There is a common concept among educators that technology is applied science - and this is the second issue that escalates the controversy between advocates of science and advocates of technology in terms of the relationship between science and technology. Jones (2007) refers to the issue of the narrow view of technology that is portrayed in science curricula. This view deems that technology is fully applied science. Gardner (1994) argued that this concept is sometimes used as a definition of technology or a general judgment of the relationship between science and technology. The impact of this concept has penetrated schools and has caused most teachers to believe that technology is applied science. For example, in New Zealand, the study conducted by Jones and Carr (1992) showed that all teachers understand technology in terms of the application of science. This issue led us to ask: Is technology just the application of scientific knowledge? Naughton (1993) answered this question by saying “No” and justified that by giving many examples of activities that are purely technological. He used the construction of Durham Cathedral in the eleventh and twelfth centuries as an example of a great technological achievement. The builders did not have scientific knowledge about the properties of the materials used to build the cathedral but they were nevertheless able to solve problems that faced them without using scientific principles. He asserted that the cathedral builders applied the knowledge they had inherited from their ancestors that shapes what is called, ‘Craft Knowledge’ - knowledge that is acquired through practical experience (Brown & Mclntyre, 1993). Naughton’s position was supported by Custer (1995) who gave examples that confirm technology is not applied science. The first example is that stone-tool manufacture flourished for over two million years before the development of the mineralogy and geological disciplines. The second is that the development of the cotton gin and steam power were technological achievements before they were developed by using modern scientific methods.

Deep analysis of the issue regarding the belief that technology is applied science was given by Lebeaume (2011). He believed that the confusion about the experimental approach in its epistemological and pedagogical aspects of science and technology made it difficult to clearly define technology education. He disagrees with most researchers who think there is no difference between the experimental aspects of technology education and science and he disagrees with de Vries's position. He cited de Vries (2005) who explained that technology education is not simply about the method of experimental science but about the foundation of practical science. Accordingly, technology is not applied science but it contributes to develop the praxis of science. In addition, pedagogical confusion occurs when teachers cannot distinguish between the epistemological point of view of science and technology (what pupils learn in each subject) and the pedagogical activities of science and technology (what pupils do in each subject). de Vries (2001) encouraged educators to use the historical material of science and technology as a pedagogical strategy for teaching science and technology. Applying this strategy could help science and technology teachers to draw a line between the purpose and the contents of the two subjects.

"Teaching technology education as a sub-subject to science will be inadequate to help students to understand the role of technology in society" (Jones, 2007). To address this issue, Jones suggested that the introduction of Science, Technology and Society (STS) can enhance the learning of science and technology in relation to society and thus help students to expand and to develop a more robust understanding of the impact of science and technology together on society. This concept of STS was one of the three main streams identified by Layton (1990, cited in(Lebeaume, 2011) on how technology exists alongside science: namely, technology as applied science, experimental approach of devices, and the science-technology-society concept. The last stream of science-technology-society equips students to understand science and technology within social, cultural, economic and political contexts, and this concept has recently been expanded as science-technology-society-environment (STSE) that addresses the environmental, moral and ethical issues (Hodson, 2009).

Ethics in Science and Technology

Usually, teaching science and technology raises controversial ethical issues that require teachers to be conversant with scientific and technological ethics. Thus, teachers should have sufficient knowledge about ethics in science and technology to assist them to present these ethical issues in the classroom. Reiss (2003) argued that ethics is “a branch of knowledge just as other intellectual disciplines, such as science, mathematics and history” (p. 15). In another publication, Reiss (1999) quoted four suggestions for teaching ethics in science from Davis (1999). First, teaching ethics might tend to heighten the ethical sensitivity of students. Secondly, teaching ethics in science might increase the ethical knowledge of students. Thirdly, teaching science might improve the ethical judgment of students. Lastly, teaching ethics in science might make students better people in the sense of making them more virtuous or otherwise more likely to implement normatively right choices.

In terms of ethics in technology education, it has become obvious that values and technology education are merged and interwoven (Custer, 2007). He argued that in this era, it has become practically impossible to disengage technology and its forms from ethical implications because ethics and values shape and lead demand for new technologies and they reflect what we apprise. He also identified some ethical topics in technology education presented by the technology teachers: the environment and conservation, consumption and consumerism, appropriate technology, the impact of technology on social structures, and the impact of technology on individuals. He considered these topics to be very important ethical issues because they represent arenas of significant public debate and concern, and they are generally within the range of awareness of technology educators.

A framework for understanding the relationship between Science and Technology

Based on the review above, technology and science can be seen as separate disciplines that have elements which overlap and interact. As such, they will require different curricula – though an understanding of the relationships should improve the teaching of each. Almutairi's model (Almutairi, 2014) of relationship between the two (see in Figure 1) shows this separation but also indicates points of interaction. The two major divisions (the first for key aspects of science, the second for technology) represent the argument, presented in this paper, that the two fields need to be considered as distinct. Linkage between the two fields, though, is represented by arrows – again these are based on the preceding review. An understanding of these components and the relationships between them should provide the teacher with a framework to support the development of curriculum and teaching plans. This section provides an overview of the components of the model and further details about the proposed points of interaction.

The top arrow between the two fields represents an important feature of the relationship between technology and science: that scientific knowledge sometimes develops from improvements in technology. A science teacher who understands the limits of testing scientific theories will better be able to inform their students about such theories. Although many theories develop from testable hypotheses, some major scientific theories remained as sound and justifiable arguments prior to technological advancements providing the tools for formal testing. For example, some of the main elements of Einstein's theories have only been tested relatively recently because the tools have been developed to allow such formal empirical testing – indeed, many theoretical physicists of Einstein's day were decades ahead of formal testing of their views because of technological limitations. Developments in telescopes/microscopes, computing and computer modeling, lubricants, fuels and the machines to extract and process them, etc., have all led to the ability to test and extend scientific theories. Models of how the brain works developed by neuroscientists were based on post-mortem and brain damage prior to the invention of brain imaging instruments. An understanding of the difference in the tools available to the scientist should lead to improved understanding of how theories have developed, why some odd theories by today's standards were perfectly plausible when proposed, and how current theories also have their limitations. For example, even though brain imaging techniques have advanced scientific understanding of how the brain works, the tools are not without limitations: e.g., in most cases testing is time limited and movement is highly restricted – hence, testing of theory is still highly limited by technology. An awareness of this relationship between science and technology should allow the modern-day teacher to understand some of the limits in scientific theory.

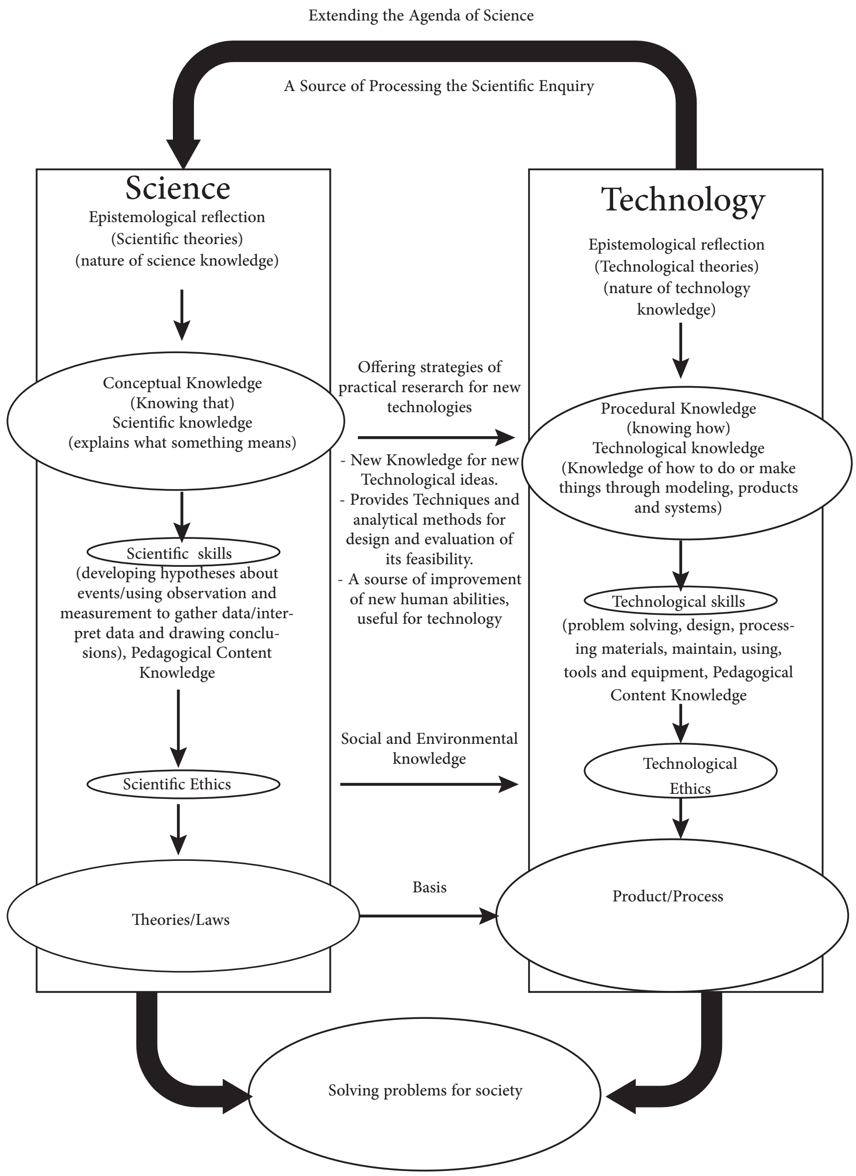

Figure 1: Almutairi's Model of Relationship between Science and Technology (2014)

Source: Almutairi (2014)

Similarly, a technological need may lead to scientific advancements. Areas of scientific knowledge may have odd gaps because the needs at the time were elsewhere: present-day improvements in scientific understanding of how materials interact are much to do with the need to develop structures that can withstand assault; and modern environmental science is as much technological advancement as purist theoretical testing. Clearly, though, both theory and tools will be bound by the needs of society. Hence, the arrows at the bottom of the diagram act as a reminder that both scientific theory and technological advancement in such areas as environmental science will be limited, or motivated, by societal views about its importance and the success of the solutions developed. Again, an understanding of these inter-relationships will provide the teacher of both science and of technology with the tools to improve the understanding of their students.

Technology is also advanced and limited by scientific knowledge – represented in the smaller arrows in the middle of the model. A teacher of technology would be limited if they did not understand some elements of the theories that led to the development of a tool/product. However, even the simple process of production is often bound by what we would see as scientific methods. It is rare to find production techniques focus on random trial-and-error. Typically, production follows principles by which scientific methods are bound. The methods for testing a theory are highly related to the methods that would be used to develop and test a product. Even when a product is based on improvements in that other product, the methods used for refinement and effectiveness assessment are typically those recognized by scientific enquiry. Although technological production might be bound by financial requirements and goals, it is a rare investor who would not need at least some evidence that a scientist would recognize – and it would be a rare product that would end up in a market without at least some history of scientific testing. Indeed, ethical considerations that are often used as the basis for allowing products onto a market can find their origins in scientific theory. Using a representative sample to test a product is based on mathematical theory; animal testing of new drugs is based on biological theories about relationships across organisms; and even the view that a product or process should not cause harm can be traced back to the bases of medical science theory as well as practice. Hence, knowledge, theories and even skills developed in science will form a basis on which to develop technological advancements – and, again, the teacher with an understanding of these relationships should be better able to impart to their students, understanding, as well as the ability to seek further knowledge.

Conclusion

Clearly, there has been much debate about understanding the relationship between science and technology that has led to a lack of general consensus on this issue. Some factors have played a role in raising this issue, factors such as the historical background of science and technology and the epistemological points of view of both subjects. However, a study of the literature shows that some attempts have been made to establish a closer connection between these two crucial disciplines in human sciences. Encouraging teachers to have a better understanding of the nature of science and technology (epistemological foundation) would help them to identify the relationship between the two.

This article has developed a pedagogical model that represents the relationship between science and technology and, in doing so, has attempted to identify the nature of that relationship. The model also aims to help science and technology teachers to understand that while technology and science are different disciplines, there is a connection between them that contributes the production of useful solutions to problems that face society and the environment.

Affiliations

Abbad Almutairi# , John Everatt, Paul Snape, & Wendy Fox-Turnbull
College of Education
University of Canterbury
#abbad.almutairi@pg.canterbury.ac.nz

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