Chapter 54
Technology in Science Education: Context, Contestation, and Connection

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One of the difficulties in writing about technology in science education is the perceptions that people have of technology are frequently associated with computers or educational technology (Cajas 2001). In fact, many national curricula, undergraduate and graduate courses in science education have sections on technology. However, these are often about using computers or multimedia to teach science concepts or processes. This represents a limited view of technology. The use of computers, as one of many educational technologies, provides important tools for the enhancement of learning across all curriculum areas but should not be equated to technology education or limit technology in science education to just the use of computers in the teaching and learning of science. Technology has played a central role in human societies and Roger Bybee (2000) notes that in late 1999, the Newseum, a journalism museum in Virginia, conducted a survey of American historians and journalists to determine the top 100 news stories of the twentieth century. He notes that in the top 100 headlines in the twentieth century, an estimated 45% were directly related to technology. Yet, as Roger Bybee notes, for a society deeply dependent on technology, and particularly in this so-called knowledge age, we are largely ignorant about technological concepts and processes, and the factors that underpin technological development and innovation. Also the lack of general notions of technological literacy is compounded by the other misconception that technology is simply applied science. Hence, we need to establish a new understanding of technology and in this case its relationship to science education. Technology in science education and the interdependence of scientific and technological literacy are becoming more prominent in the science education literature. For example, there are special issues on technology education in the journals of *Research in Science Education* (2001) and *Journal of Research in Science Teaching* (2001).

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The inclusion of technology within science education has been a site of debate, classroom research, and curriculum innovation.

This chapter explores the science, technology and society (STS) movement and the various stages it has been through in the last 25 years. Science teachers' perceptions of technology are explored and the implications they might have on the teaching and learning of science. The introduction of technological applications in science and the outcomes of this approach are explored as is the introduction of technological problem solving in science classrooms. The role and place of technology in science curricula is discussed as well as the possible integration of science and technology in the curriculum and classroom.

Relationship Between Science and Technology

The relationship between science and technology is a complex one. An analysis of both the nature of science and the nature of technology shows that there is a complex relationship between the two. Consideration of the nature of technology indicates that technological knowledge and practices are socially constructed and context dependent and where human mental processes are situated within their historical, cultural and institutional setting (Wertsch 1991). Therefore, technology is an activity that involves not just the social context, but also the physical context, with thinking being associated with and structured by the objects and tools of action. Technology is based within a philosophical, historical, and theoretical context (Mitcham 1994). It is its characteristic as an activity, as well as a body of knowledge that is salient. Technological activity makes the idea of practice most central, and hence the importance of technological practice. Technological practice is primarily about doing technology, as well as studying it and creating technological knowledge. This does not deny that those who do technology create knowledge either through technological activity or in a theoretical fashion or that there is unique technological knowledge. The uniqueness of technological knowledge, processes, and skills has not always been recognized in general education, although literature in the area is increasing (Jones 1997). People use technology to expand their possibilities, to intervene in the world through the development of products, systems, and environments. To do this, intellectual and practical resources are applied. Technology includes control, food, communications, structural, bio-related, materials, and creative design processes. From a research and development perspective, Paul Gardner's (1994) review on science and technology had a significant influence. He argued that the relationship between science and technology could be seen in four ways:

1. Technology as applied science
2. Science and technology as independent communities
3. Technology as giving rise to scientific understanding
4. Science and technology as equal and interacting communities

Technology can be utilized in a variety of ways in science education but, in doing so, it is important to have a clear concept both of the nature of science and the nature of technology. Too often in the past a limited view of technology in science has limited both the learning of science and the learning about technology. When technology is viewed as applied science it is assumed that there is a linear relationship in which science generates technology, and when this view is held, the story of a technological development is projected through the science lens (Gardner 1995).

It is therefore important that some of this complexity is apparent in science education. Unfortunately in the past a simplistic relationship of technology as applied science has held sway. It is time for a reevaluation of this relationship (Cajas and Gallagher 2001). Discussions about this relationship often were fruitless because a too simplified image of that relationship was used. The technology as applied science paradigm is well known. Defenders of this paradigm had no difficulties in showing examples in which this idea applied well. There is scarcely any doubt that the transistor would not have been invented in the Bell Labs without the use of solid-state physics. However, at the same time others could come up with equally valid examples for rejecting the technology as applied science view. They could come up with the example of the hot air engine that was invented at a time when the engineer's knowledge of thermodynamics was not very adequate. So valid cases could be used both for defending and for rejecting the technology as applied science paradigm. As Marc de Vries (2001) notes, it is important to distinguish between different types of technology because for some technologies the technology as applied science paradigm does apply, for others it does not. In some cases science and technology can be inextricably linked. For example, the laws of physics can limit technological innovation, and scientific activity can be constrained by factors such as commercial advantage. However, even in these instances, the purpose of science and technology is different. For the scientist the purpose is developing a greater understanding of the natural or even the made world. The purpose of a technologist is to intervene in that world and to change it in some way. This means that technological solutions will often be specifically situated, whereas scientific solutions are usually thought to be more generalizable.

Marc de Vries (2001) notes that the history of industrial research laboratories can offer a good opportunity for studying the complex relationships between science and technology. A good insight of these relationships is relevant for shaping a sound concept of science and technology in both science education and technology education. In his article, three different interaction patterns are derived from the history of industrial research labs (in particular the Philips Natuurkundig Laboratorium), namely (1) science as an enabler for technology, (2) science as a forerunner of technology, and (3) science as a knowledge resource for technology.

Science, Technology, and Society

The 1980s saw an attempt to include the theme of science, technology, and society (STS) in the research and curriculum agenda. Peter Fensham (1987) identifies 11 dimensions or aspects of STS learning. These are: the relation between science and technology; technocratic/democratic decision-making; scientists and socio-scientific decisions; science/technology and social problems; influence of society on science/technology; social responsibility of scientists; motivation of scientists; scientists and their personal traits; women in science and technology; social nature of scientific knowledge; and characteristics of scientific knowledge (scientific methods, models, classification schemes, tentativeness). The STS movement began due to a combination of factors, including the 1960s' growing concern that science education had become divorced both from its social origins, and from the social implications of scientific endeavor. This was often expressed as the "social relevance of science" (Fensham 1987, p. 1). There was also a push for science education to become more technology related. Introducing STS maybe seen as being a way to add to conceptual development or as alongside conceptual development in science (Hughes 2000). Joan Solomon (1988, p. 379), in fact, states that "STS has emerged as a discipline with a discernable history and development." Although STS in some places has become a subject in its own right, in many countries, an STS focus has often been an add-on in the teaching of science. It is important to note at this point that while technology is conceptualized within STS it is in practice very much aligned to applied science. An STS approach has also expanded into thinking about socio-scientific issues in science education.

The introduction of biotechnology as an area of research and development, including curriculum development in science education has provided a means to develop a much more research-focused agenda around science, technology, and society. Advances in biotechnology have social, political, economic, and wider cultural implications and present society with ethical issues and dilemmas which require informed citizens capable of contributing to public debate. An improved understanding of socio-scientific issues among young people will help to ensure they have an informed, defensible view and that they understand, for example, the rationale for national initiatives to combat environmental issues involving genetically modified organisms (Dawson 2003). As part of the reason for including social and technological issues is also to introduce values and ethics into science, it seems clear that students need opportunities to develop, reflect on, and justify their bioethical values. Vaille Dawson (2003) identifies the multiple skills involved in students' ethical decision-making: ethical sensitivity (in identifying the dilemma), ethical reasoning (identifying and weighing up arguments for and against different decisions), and ethical justification (reaching and justifying a decision). While approaches derived from STS programs, for example, case studies, structured debates, oral presentations, and scenarios, can be adapted to promote student questioning and decision-making about societal issues, many of these do not delve deeply into the social and ethical aspects.

Perceptions of Technology by Science Teachers

Teachers' concepts and practices have shown strong links with the initiation and the socialization of teachers into subject subcultural settings (Goodson 1985). Therefore, teachers have a subjective view of the practice of teaching within their concept of a subject area (Goodson 1985). This view is often referred to as a subject subculture, and leads to a consensual view about the nature of the subject, the way it should be taught, the role of the teacher, and what might be expected of the student (Paechter 1991). As technology was being increasingly linked with science education and as an area of study in its own right, concern was raised as to what were teachers' and also students' perceptions of technology. In the study conducted by Alister Jones and Malcolm Carr (1992) on teachers' perceptions of technology and technology education they found that all the science teachers who were interviewed saw technology education in terms of applications of science. In terms of teaching, technology was perceived to be a vehicle for teaching science and often something extra to the conceptual development in science. Many of the teachers at the primary and intermediate school viewed technology in terms of computers. For these teachers technology meant using computers or other technology to solve problems. Teachers also mentioned problem solving in relation to finding out how things work. Technology is seen as a mechanism for solving a problem or as a vehicle for approaching a particular type of problem solving, that is, finding out how things work, particularly in science at the secondary school level.

Judy Moreland (1998) reported that although elementary teachers stated they needed to learn more about the teaching of technology, they felt they had enough skills and understanding to be teaching technology and could do it in the classroom. One teacher with a science strength set the students applied science tasks (design a hot balloon after studying flight). Technological principles were not involved. The criteria were in terms of why things happened and a narrow focus of outcomes. Anne Northover (1997) noted that all the high school science teachers she worked with viewed technology as being applied science and technology as skills and skill development. The teachers went for minimal change and added technology into existing programs rather than developing new ones or new learning outcomes. She found that these teachers generally expressed an interest in technology and commented on the motivational aspects of technological activities. The dominant science subculture in schools proved to be a powerful conservative influence. Teachers who showed changed views of technology and biotechnology in the teachers' development program, by the end of their teaching often had reverted to the perspective held initially. In fact, where teachers did make changes to their initial perceptions, the cognitive dissonance set up by the disparity between their views and their practice was often resolved by reverting to a previously held view.

The strategies developed by the teachers in their classrooms when implementing technological activities were often positioned within that particular teacher's teaching and subject subculture. For science teachers these subcultures are consistent and often strongly held. The subcultures had a direct influence on the way the teachers structured the lessons and developed classroom strategies. Teachers developed strategies to allow for learning outcomes that were often more closely related to their science subject subculture than to including technological outcomes. Teachers entering areas of uncertainty in their planned activities often reverted to their traditional teaching and subject subculture. Teachers' existing subcultures in terms of teaching and learning, subject area, and school, in association with their concepts of technology and science, influence the development of classroom environment and strategies, and consequent student activities.

Introducing Technological Applications in Science

The introduction of technological applications was seen as a means of increasing the relevance and authenticity of science. Research in science education that explored the use of technological applications for the teaching of science, suggests such contexts do have a positive effect on students' learning of scientific principles and concepts (e.g., Jones and Kirk 1990). This research is in keeping with international research findings on the importance of context in student learning (Hennessey 1993). Alister Jones and Chris Kirk (1990) found that in using such applications as earthquake monitoring systems and baby breathing monitors, students indicated that these technological applications helped them to remember scientific concepts involved. No change was recorded, however, if the applications were used as an add-on either at the beginning or end of a lesson. The students also commented that the use of such technological contexts also provided frameworks for the construction of further scientific concepts to those specifically targeted. Another important outcome from this research was the significant increase in the student's level of confidence, interest, and enjoyment in science generally. Care must be taken, however, that the technological context used is appropriate to the students' interests and the scientific content, and that it is presented as an integral part of the learning experience rather than an add-on for the sake of sparking interest. Susan Rodrigues and Beverley Bell (1995) explored the role and effect of context on female students' learning of oxidation and reduction. Using such technological applications as breathalyzers, and hair perming and coloring systems as contexts, they found that not only did students become more interested in the scientific concepts of oxidations and reduction, but also there was an increase in the number and quality of classroom interactions both with each other and the teacher. The students appeared to take ownership of their learning.

There is an increasing body of research that supports the use of technological applications in science education. It would appear that student learning in science could be enhanced by using technological applications in order to increase their understanding of scientific concepts and principles, as well as increasing their enjoyment of science generally.

Technological Problem Solving in Science Classrooms

There have been many attempts to introduce technological problem solving in science classrooms. However, classroom observations undertaken in science classrooms when technology problems have been introduced have shown that the science classroom culture and student expectations can influence the way in which students carried out their technological activities (Jones 1994). The students in the science classrooms enjoyed carrying out technological problem solving and their teachers reported considerable enthusiasm for these activities. However, subject subcultures were a major influence on students' expectations of classroom practice, with regard to both themselves and their teacher. For example, the solutions that the students sought were often in terms of traditional solutions utilized in their prior experiences of the science classroom. When questioned, these students often clearly stated that they could have done more toward solving their problems, but they consciously limited themselves to what they considered was appropriate within the science classroom. Mike Forret (1997) investigated the early learning of electronics. He used problem solving and contextual approaches to introduce electronics to students. He found that students had an interest in electronics, had enhanced practical competence in constructing circuits and enhanced problem solving. Ian Ginns et al. (2007) highlighted that science learning outcomes can be identified in some students' technological activities. These learning outcomes were related to work that the students had covered earlier in the year. However, it was noted that opportunities for extracting science principles from technological activities have not been maximized. Norton et al. (2007) indicated that introducing technology in science allowed students to think for themselves, apply logical thinking, be creative, and allow for student autonomy. The introduction of technological problem solving in science can allow for greater problem solving and strategic thinking but not necessarily enhance student understanding of technology.

When technological problem solving is introduced into science classrooms, students are interested, enjoy the experience, and in many cases learn some scientific concepts. There is very little evidence of transfer of scientific knowledge to technological solutions and little understanding of the processes involved. The technological process adopted by the students is somewhat fragmented and appropriate solutions are not forthcoming. The culture of learning in science classrooms does not appear to lend itself to helping students develop technological capability or technological literacy. The introduction of technological problem solving into science classrooms needs careful consideration if technological literacy is a desired learning outcome in science.

Technology in the Science Curriculum

The late 1980s and 1990s saw the greater inclusion of technology as an area of study in science curricula internationally, for example, in England (Hughes 2000), in the USA (Cajas 2001), and in New Zealand (Bell et al. 1995). Internationally there was also an emphasis on the inclusion of technology as a vehicle for the learning of science. However, generally science curricula portray a narrow view of technology. Such a narrow view of technology relies on a concept of technology as very much focused on applied science. As has been stated elsewhere (Bell et al. 1995), the treatment of technology as embedded in science is cause for concern as it means that other forms of knowledge, including technological knowledge, which are all essential for technology, are not apparent. It also excludes many technological innovations and developments that have no direct links to science as a discipline.

These science curricula often introduce technology for the purpose of clarifying and demonstrating the scientific principle. At higher levels of some curriculum, the focus shifted to that of investigating in a very general way the relationship between science and technology, for example, acknowledging and understanding how technological advances have aided or in fact enabled the development or major rethinking of scientific ideas. When there was a focus on learning how technological artifacts function, this was in terms of scientific principles only, ignoring technological and other knowledge bases crucial to the successful functioning of technological artifacts, systems, and environments. The principles behind technological innovation are perceived to be only those belonging to science. There is some opportunity within this aim to see how technological developments impact on scientific knowledge, and vice versa. This opportunity is constrained to those technologies fitting the applied science notions of technological developments. There is also opportunity for exploration of the effect of technological development on society. However, it is specifically stated that the means of such an evaluation should be through the application of scientific knowledge.

Biotechnology is a curriculum area that is often highlighted as an example of where science and technology come together as equal partners. In most international curricula biotechnology appears within senior science and biology and correspondingly its classroom implementation provides examples of technology as applied science. However, this narrow focus of biotechnology may limit the exploration of sociopolitical or ethical dimensions of biotechnology in classroom programs, and provides limited opportunities for students to develop rich scientific and technological literacies (France 2007). France found that the position of biotechnology in science curricula internationally tended to place it within an applied science framework (technology as applied science). An expression of such applied science examples are: microbiological processes being identified within human health and disease, examples to illustrate anaerobic respiration (bread and ginger beer making), and the application of microbial degradation in waste disposal and composting. What are missing from most of the curricula are opportunities for discussion of sociopolitical issues as well as values inherent in technological processes. The positioning of biotechnology in this way means that technology itself is underplayed, as is the chance for students to develop a greater understanding of the relationship between science and technology and the values inherent in this. Biotechnology in terms of GM debates can put its inclusion in the curriculum more toward the discussion of controversial issues rather than consideration of a broader understanding of biotechnology in its wider context. However, the aligning of biotechnology only with controversial issues also means that students may develop a distorted view of biotechnology rather than seeing it in its fuller context. This representation of technology in science only shows a relationship in terms of science to technology as application and this represents a view of technology as being applied science. It also tends to reflect a deterministic view of technology and in fact science for that matter.

Integration of Science and Technology

The integration of science and technology is seen as a means of combining these areas. However, this can be problematic as highlighted in the previous sections. Grady Venville et al. (2002) explored in detail notions of curriculum integration and what it might mean from both a theoretical and practical perspective. They explored the nature of integration and how it is represented in the school environment. They also examined why integration should be considered and focused on student engagement and whether integration enhances learning in science. These authors highlight several studies that show an authentic curriculum related to student needs and interests and to the world outside of school, results in increased participation and engagement, and reduces alienation. In their paper they highlight how competitions such as the Science Talent Search provide opportunities for the integration between science, mathematics, and technology. They indicated that subjects such as science, when placed within an integrated curriculum that is based on content, is difficult to assess and relatively open to debate. They provide an example of integrated practice involving the use of technology-based projects. High School students worked on a technology project for 10–12 weeks that included technology, science, and mathematics research components. An example of a technology project brief was to design and produce an electric powered vehicle that could climb a steeper gradient on the standard test track than any others. The technology aspect investigated traction options, materials and construction techniques, motor mounting options, and power transmission systems. The science aspect investigated friction, gears and pulleys, torque and power transfer, and how scientific trials influenced their choice of traction, gearing, and drive options.

This is an area for further research but cognizance needs to be taken of the way in which science as a high-status subject and teachers' and students' perceptions of and understanding of the relationship between science and technology will influence the outcomes in the classroom. In integration of science and technology then, technology is often seen as the context to teach science and problem solving rather than teaching about both science and technology.

Conclusion

This chapter has considered ways in which technology has been included in science education research and development. A broad notion of technology was taken in terms of people using technology to expand their possibilities and to intervene in the world through the development of products, systems, and environments. To do this, intellectual and practical resources are applied. Technology includes control, food, communications, structural, bio-related, materials, and creative design processes. It is important that teachers and students develop an understanding of technology and science as two areas that can interact but are also distinct in nature. Technology is a discipline in its own right (Mitcham 1994) and is not a subset of other learning areas. For example, technological knowledge is not reducible to science, mathematics, or social science. Science must not be seen as a gatekeeper for students undertaking further work in technology, as this will limit students' learning in both fields.

The rationale for the introduction of technology in science has centered on an attempt to increase the relevance and authenticity of science to students. There is evidence that when this is introduced in an appropriate way, there is increased enjoyment and even improvement for some students in science achievement. Technology was essentially perceived as applied science and this influenced the way it was introduced to the classroom. The introduction of technology and also social aspects allowed for values and ethics to be introduced into the science classroom, particularly in relation to biotechnology in biology classes. The introduction of technology into science classes has seen technology dominated by the science subculture. When technological applications were introduced in a themed approach rather than as an add-on, students were more likely to be engaged in science, enjoy it more, and achieve both in science and technology. In the science curriculum, technology has been essentially introduced as applied science although at the higher levels of the curriculum, technology is seen as advancing science. However, the focus was on the direct links with science rather than social or technological principles. The introduction of STS and technological applications can enhance the learning of science concepts and increase students' interests and motivations. However, if technology is taught as a subset or as subservient to science, then this will be detrimental for student learning of a clear understanding of technology.

The potential of technology to make a difference in the teaching and learning of science has probably not reached the potential we thought it might when we began exploring its introduction 25 years ago. Technology in science education is used as a context and also provides connections for students. However, its place is still contested.

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