Technology education beyond the 'technology is applied science' paradigm

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Guest Article

Technology Education:
Beyond the "Technology is
Applied Science" Paradigm

Marc J. de Vries

How Important is Science for Technological Innovation?

In the early days of the development of philosophy of technology as a discipline that reflects on technology, one finds the opinion that technology is applied science. (Bunge, 1966 speaks about "technology" and "applied science" as "synonyms"). Gardner (1994) shows how Francis Bacon already defended the thesis that technology should be applied science and that we find this opinion time and again in later literature. It is then suggested that there is a more or less straightforward path from that scientific knowledge to the technological product. This opinion for some time functioned as a paradigm for the philosophy of technology.

Nowadays we find much opposition against this paradigm and it is clear that we are going through a revolution in the Kuhnian sense (Kuhn, 1970) from one paradigm to the next. But what will be the next paradigm? That is not always so clear. Some recent literature tends to swing towards the opposite and suggests that technology precedes science. The example of the steam engine is mentioned to illustrate that. Elsewhere, I described the development of a successful corkscrew by a Dutch company named Brabantia (de Vries, 1994a). In that study it became evident that scientific knowledge had only a very limited influence on the development of the product and the explanation for the great success of the corkscrew is only to a small extent based on clever use of knowledge of natural phenomena. Rather the success is the result of a clever use of the combination of scientific-technological know-how and know-how of social (market, juridical) phenomena. The case studies in aeronautics by Vincenti in his well known *What Engineers Know and How They Know It* confirm that. When he surveyed the various types of know-how that helped engineers to design their aircraft, he found that scientific knowledge is only one of several types (Vincenti, 1990).

Marc J. de Vries is Assistant Professor, Philosophy and Methodology of Technology, Faculty of Technology Management, Eindhoven University of Technology, Eindhoven, The Netherlands. Dr. de Vries presented this paper at Virginia Tech in March 1996, as a part of the Technology Education Program's "Distinguished Lecture Series" and Fiftieth Anniversary commemoration activities.

Technology in Science Education

The "technology is applied science" paradigm in the philosophy of technology is reflected in education. Apart from traditional subjects like industrial arts or craft, we find elements of technology in science education. Science education for many years used to be a rather abstract subject where it was difficult for pupils to recognize the relationship between the knowledge that was taught in science lessons with their daily life. This relationship is found mainly through the technological products they find all around them and therefore a trend emerged in science education to show how scientific knowledge was applied in technological products (de Vries, 1994b). When one considers the course material that resulted, one can easily recognize the "technology is applied science" paradigm.

In almost all cases there seems to be no process in between the scientific knowledge and the technological product. The success of the product this way seems to be in the scientific knowledge. This paradigm could be used to support the "science for all" ideal that was preached as a result of for example, the Sputnik shock. Teach pupils scientific knowledge and later they will be the engineers that will be able to apply this knowledge for developing technological products. In the latest Workprogramme of the Targeted Socio-Economic Research (TSER) of the European Commission's Fourth Framework Programme, one of the research tasks is "Science and technology teaching as components of general education." But this is explained as: "approaches, concepts and methods in science teaching (including history and philosophy of science as a way of improving science understanding). Comparative research on the role of scientific education in the building knowledge and general education" and no reference is made to technology education at all!

As we saw before, the "technology is applied science" paradigm is challenged now. Does that mean that we also can move away from "science for all" and replace it by "Technology for all, science for some" or "Technology for all Americans" as is the title of a nationwide project in the USA (Martin, 1995)? Can we reduce the role of science education to that of "gate keeper" (Gardner, 1995), which it already seems to fulfill in many cases? To answer that question wisely we have to consider the relationship between science and technology somewhat more carefully.

Science Does Play a Role, but Not the Only Role

The example of the steam engine that is often quoted to attack the "technology is applied science" paradigm is suggestive of course, but not sufficient to do away with this paradigm. Examples of other technological developments do seem to support that paradigm. Elsewhere I have described the case of the development of Active Matrix Liquid Crystal Displays (AMLCD's) in a small Dutch firm (de Vries, 1996b). Here the most important breakthrough in the development was the new knowledge that the Philips Research Laboratories produced on demand by the AMLCD firm. A study of the development of the transistor in the Bell Laboratories by Sarlemijn shows the same phenomenon. Here too, it was only thanks to sophisticated scientific knowledge of microstructures that the product could be developed. In both cases, however, we also see that social factors play a role, but in a quite different

way than for example, in the case of the Brabantia corkscrew. In the case of the Brabantia corkscrew, market requirements had a practical impact on the product development from the very beginning of that process. In the case of the AMLCD and the transistor, the influence of market factors could only become practical late in the process when the functional problems of the product had been solved in principle through the application of the scientific knowledge.

The Need to Differentiate Between Types of Technologies

None of the previous cases show us that the "technology is applied science" paradigm gives an adequate description of the technological innovation. In all cases, factors other than natural phenomena and the use of knowledge about those phenomena also played a role. And the role that scientific knowledge played differs substantially between the various cases; sometimes it is dominant in the early and crucial stages of the development, sometimes it is almost absent. This makes it difficult to make any general statement about "the relationship between science and technology." In fact there appear to be several possible relationships between science and technology. Many discussions in literature were fruitless because authors wanted to defend one overall theory on the relationship between science and technology without realizing that one needs to differentiate between different types of technology if one wants to give an adequate description of the role of science of technological innovations.

Based on the case studies that have been mentioned above and other cases (e.g., the Philips Stirling engine) one can identify at least three different types: experience-based technologies, macrotechnologies and microtechnologies. The Brabantia corkscrew is an example of an experience-based technology. Here the role of science is limited to knowledge of natural phenomena that was gained by experimentation and not by deriving it from fundamental theories. Such deductions are made in macrotechnologies, where the fundamental theories are the classical ones (mechanics, thermodynamics and electromagnetic) that are all concerned with macroscopic structures. Deductions from theories on microstructures play a vital role in microtechnologies, of which the transistor and the AMLCD's are examples. At first sight, this differentiation may seem similar to Bame and Cumming's differentiation into caft and machine, machine and power, and power, atomic and cybernetic levels of complexity (Bame and Cummings, 1988). But it is different in nature

As we have seen, the relative influence of scientific-technological and social factors is different for the different types of technologies and also varies as the development process goes on. Three caveats should be mentioned here. In the first place most products are combinations of elements some of which have been developed in an experience-based way, others in a macrotechnological way and others in a microtechnological way, as Sarlemijn and I described in the case of the Philips Plumbicon, a television pickup tube, that was developed in the Sixties (Sarlemijn and de Vries, 1992). In the second place, sometimes there is a transition in the way products are developed. Bridges, for example, for a long time were developed purely on the basis of practical rules of thumb that were the result of many years of experience in designing bridges. Strauss (1964) gives examples from L. B. Alberti and C. Fontana in the 17th century. But later, due to

a new type of engineers' training program in the French Ecole des Ponts et des Chaussees, civil engineers designed bridges by deriving and applying equations from Newton's laws of classical mechanics. And still experience-based knowledge plays a role in the design of sophisticated bridges, which makes designing them often a risky enterprise (Petroski, 1994). The length of the cables in a suspension bridge can still not be predicted exactly, but is adapted even during the construction of the bridge. This is not unlike practice in the time of Dufour, who designed many of those bridges in the previous century.

New Paradigms and Their Weaknesses

The abolition of the "technology is applied science" paradigm has caused a variety of new paradigms. Some of them have gained field very rapidly, such as the social constructivist approach (Bijker), the actor-network approach (Callon) and the systems approach (Hughes). Each of these approaches focus entirely on the role of social actors in technological innovations. When Pinch and Bijker (1994) for example, describe the development of the bicycle, they state that a bicycle primarily is what relevant social actors define it to be. In the early days of bicycles, boys found it to be a suitable device for showing their courage and safety requirements were absolutely not desirable. Later on, this changed when one started to see it primarily as a transportation means for all people. Likewise, Callon showed how the development of the electrical car in France can largely be described as the result of a struggle between various social actors (business industries, scientific laboratories, and government).

It is useful to remark that it is a misunderstanding to think that science is less sensible to social influences and more objective and neutral. Pickering (1984) for example, has shown how scientific knowledge too can be described as a social construct. One can question if any of these approaches does justice to the role of scientific and technological factors. All of them seem to belong to what Mitcham (1994) called the humanities approach as opposed to the engineering approach. Based on case studies Sarlemijn and I proposed a different approach, which we called the "STeMPJE" (Sarlemijn and de Vries, 1992; Sarlemijn, 1993). It has more the character to look at technology "from inside." STeMPJE is the acronym that represents all factors that we found to be relevant for describing technological innovations: scientific, technological, market, political, juridical and aesthetic factors. Several studies by mechanical engineering students in our Science, Technology and Society program showed the usability of this approach to help business companies determine their products strategy and not only for analyzing historical cases.

Consequences for Technology Education

What does all this mean for technology education? Is our present practice in line with this or do we need to make changes? In the first place we can state that pupils seem to have great difficulties in recognizing the role of science in technology. Their opinion varies from "science and technology are the same" to "science and technology have nothing to do with each other." International PATT (Pupils' Attitudes Towards Technology) studies initiated in the Netherlands and later extended to other countries and the U.S. (Bame, Dugger

and de Vries, 1993), showed that pupils mainly see technology as a collection of products. This is a one-sided image of technology, because it lacks a process awareness. The way science education now tends to integrate elements of technology by focusing on the application of his knowledge in existing products will stimulate this product oriented thinking about technology.

We also see that pupils hardly realize the variety of types of technology; they mainly see technology as "high tech" (or microtechnology). Sometimes they explicitly reject examples of experience based technologies as being technology (e.g., a wooden spoon or a plastic cup). This is at least partially caused by the way technology is presented in popular magazines, television programs, and so forth. Technology education has the task to make this concept of technology broader and more varied. The differentiation between types of technology as sketched above can be helpful to identify how to do this. We can only give pupils a proper understanding of the role of science in technological developments when we make them aware of the differences between different types of technology.

A Separate Subject: Technology?

As we have seen, the danger of integrating technology into science education is that it does not do justice to the real relationship between science and technology. But how about the other option: making technology education a separate subject? This option is challenged by the question whether or not it is possible to define a body of knowledge and skills called "technology" that we can treat as a separate subject (Herschbach, 1995). What could be characteristic of such a body of knowledge and skills? At least one can think of the "system" concept that seems to be integrated in all engineering fields (Hubka and Eder, 1984) and is already used in technology education as well (see e.g. Wright, 1992). International trends show that the answer to this question more and more is found in the design process as the heart of technology. And even though the academic background for the school subject technology is far less than science education, there is a growing discipline "design methodology" as part of the philosophy of technology that can serve as a resource for determining how we should give pupils a realistic image and experience of design.

The short history of this discipline has shown that the naive idea that there can be one ideal prescription for any design process is not realistic. The need to distinguish between different design processes for different products is well established now, even though design handbooks with general flowchart diagrams for design processes are still published that seem to deny this (e.g., Pahl and Beitz, 1988). In technology education, we often have not discovered this yet, given the fact that several textbooks for technology education still seem to try to teach one overall scheme for designing to pupils. Maybe this can be useful to help pupils getting started with designing, but soon we should make them aware that different products may require different strategies for designing. Thereby, we should realize that in elementary and junior high school we probably have to limit ourselves to experience-based and macrotechnologies, because microtechnologies are often too abstract and advanced to deal with in those classes. The further we move on toward senior high school, the more

differentiated the concept of technology pupils hold becomes. In the training of future technology teachers, all types of technologies may be dealt with and student teachers should learn to understand the differences between them.

Quality as a Key Concept in Technology

As we saw, design is a key activity in technology that illustrates that it is possible to define a body of knowledge and skills called "technology." A concept that also illustrates this as typical for technology is "quality." This concept originally had a limited meaning in terms of reliability and non-failing behavior. Recently it went through a paradigm shift and came to mean "anything that adds to the attractiveness of the product for the customer." Quality is no longer limited to quality control at the end of the production process, but is now required in the design process. Dramatic changes in product creation processes have been initiated to realize this. In "integrated product design," one takes into account all later phases of the product (manufacturing, assembly, packing, distribution, sales, use, repair, maintenance, recycling). Tools have been developed to do that: quality function deployment, value analysis, design for assembly, failure mode and effect analysis, and so forth. One can go even further and start up the development of the later phases of the life cycle during the design process, and this advanced strategy is called "concurrent engineering." In technology education, we do not yet seem to have discovered this new trend towards quality thinking. Elsewhere, I have proposed to implement simplified versions of quality methods in technology education to make pupils aware of the importance of the quality concept for contemporary technological innovations in business corporations (de Vries, 1996a). Certainly at the level of technology teacher training projects, can be done in which student teachers learn to apply such tools themselves. Thus, they are enabled to help their pupils gain some understanding of those tools in their lessons.

Dealing with Design Properly in Technology Education

In summary, the most important lessons that we can learn from design methodology for teaching technology are the following (see also de Vries, 1992). First, we should avoid a naive use of generalistic design prescriptions. As in the reality of the industrial practice, we will find out that methods need to be adapted to the needs of the specific product that is being designed and do not have the general character that popular literature suggests they have.

Second, we should help pupils to integrate knowledge (scientific, but also other forms of knowledge) into their design processes. This is the only way design processes can be successful, as recent educational research has shown. It is evident that there is a role for science education here and that science education remains a crucial part of general education even where technology education has gone beyond the "technology is applied science" paradigm. Layton (1993) has indicated the various roles science can play for technology: 1) as a cathedral of fundamental research, from which experimental and quantitative methods for investigation and mathematical modeling can be drawn 2) as a quarry, from which scientists can pick out items they think they can use, and 3) as a company store, in which more dedicated "products" are provided for

technologists. The last mentioned function is quite necessary. As studies by Vincenti, for example, have shown, scientific concepts often need to be transformed to become usable for technology. Third, we should realize that design processes should differ also because different people (pupils too) use different strategies for designing that fit their different personalities. Pupils can have quite different thinking preferences (in pictures or in words, more convergent or more divergent). We should not try to force them to use generalistic strategies that may not fit their personality. Finally, we should not only teach students to use scientific knowledge, but also knowledge about social phenomena (market requirements, laws, patents, political decisions, etc.). Thus they learn to recognize the complexity of real design processes, even though they do not yet need to cope with this full complexity themselves. Prospective technology teachers should learn how to guide that process and how to deal with the dilemma between a directive versus a more laissez-faire approach.

Final Remarks

It is evident that we face the challenge to move technology education beyond the "technology is applied science" paradigm. At the same time, we should not do so as if science hardly plays a role in technology. The current situation with a majority of technology teachers not having a sound science background can make this difficult to avoid. And science teachers often are hampered by the fact that they hold the "technology is applied science" idea, (Rennie, 1986). Projects that develop examples of integrating science, math and technology like the one that was initiated at Virginia Tech (LaPorte and Sanders, 1993), should be used to see how a balanced view of the relationship between science and technology may be created through practical classroom activities.

To make use of the new knowledge about the relationship between science and technology in the context of Science, Technology and Society (STS) programs, a structural co-operation between technology education programs and academic STS programs is important. The organization of the Technology Education Distinguished Lecture of Spring 1996 at Virginia Tech (co-sponsored by the STS program) is a good example of such a cooperation that can help technology educators to build a more sound academic basis for their school subject. Another need for technology education in terms of the science-technology relationship is educational research with respect to how pupils see this relationship and how their ideas may be changed in technology education. In general, the educational research basis for technology still needs to be strengthened and extended. Here a lot can be gained from experiences in science education, where many studies into the conceptions that pupils have of scientific concepts and principles have been reported (de Vries, 1994). In the building up of a sound educational research base for technology education and the translation of the outcomes to teachnology education and technology teacher training, there is certainly a challenge for all those who feel committed to technology education as a valuable contribution to the general education of all future citizens.

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