Kapitel 6: Teaching for Scientific and Technological Literacy: An International Comparison

Marc J. de Vries

Scientific and technological literacy: two distinct concepts

In the second half of the 20th century, a new domain within philosophy emerged, namely the philosophy of technology. It was a new branch on a rapidly growing tree of philosophies for specific fields of human activity. Other branches are philosophy of science, philosophy of education, philosophy of art, etcetera. One of the merits of the philosophy of technology is that it has made us aware that technology is more than applied science. The idea of technology as applied science had been popular for several decades and that is probably the reason why philosophers were not very much interested in reflecting on technology, other than its social effects. In the early years of philosophy of technology this was precisely the focus and technology itself remained a black box in this discipline to a large extent. If technology is merely the application of knowledge gained somewhere else, namely in science, than one cannot expect that anything sensational happens there, at least not before the outcomes of technology start influencing our lives. More recently, though, philosophers of technology – in many cases those who themselves also had a background in engineering sciences – were able to show that in technology new knowledge does develop. In fact, it appeared that certain types of technological knowledge even have characteristics that make it quite distinct from scientific knowledge. In particular the normative dimension in a lot of technological knowledge is such a characteristic. For an engineer it makes perfect sense if (s)he claims to 'know that' this is a good drilling machine. But for a physicist to claim to 'know that' this is a good electron is sheer nonsense. That is because normativity ('good' or 'bad') is not in the content of what physicists 'know'. If the presumed electron does not do what it is supposed to do, it is not a bad electron, but it is a different particle. Physicists cannot complain about 'malfunctioning' or 'broken' electrons. They just describe the world as it is and make no value judgments. Engineers, however, develop knowledge not only about the world as it is but also about the world as we would like it to be. In that perspective 'good' and 'bad' do feature as properties of the world as it is. The broken car does not function as it was designed for, and therefore engineers can claim to 'know' that it is a bad car. This is only one example of technological knowledge that has features that make it different from scientific knowledge.

In popular language, the distinction between science and technology is often confused. Journalists have no problem in writing that ‘scientists have invented a new . . .’, while in fact this is what engineers do. Of course, the nature of the work of these people can be such that inventing and discovering, or stated differently, between research and design, go hand in hand so closely that it is hard to tell what they are doing at any moment. But still, analytically the activity of research aimed at explaining the existing world, and designing aimed at creating a new world, can be distinguished. The outcomes of studies in the philosophy of technology have made evident that it makes sense to do that, in order to get a proper understanding of the nature of both science and technology. This also holds when discussing teaching for scientific and technological literacy. Often, one finds the two confused and usually the term scientific literacy is used only under the assumption that it covers both, while often essential components of technological literacy are missing because of the confusion of terms. Therefore, in this chapter I will constantly distinguish between the two analytically, in spite of the fact that the two often go hand in hand closely.

I will, then, use the term scientific literacy to indicate the knowledge, skills and attitudes related to science as a (primarily) knowledge-generating human activity, and technological literacy to indicate the knowledge, skills and attitudes related to technology as a (primarily) artifacts and systems generating activity. Both are valued highly in our days because we realize that we live in a society in which the outcome of technology has an enormous impact on our lives, and that scientific research is an important input for the development of technological artifacts and systems. I will use the term ‘science’ in the usual sense of ‘natural science’. Here is another possible source of confusion, because there are other sciences that also provide an input for the technological process. Economical sciences inform engineers about economic constraints to and effects of their work; psychology informs about the way users will perceive their designs, juridical sciences inform them about what is legal and what is not, etcetera. In our analysis, we must also realize that there are engineering sciences and that they are different from both natural sciences and other sciences such as the humanities and social sciences. That means that technological literacy is related to other sciences than natural sciences.

The importance and content of scientific and technological literacy

Having now distinguished scientific and technological literacy, we can search for the relevance of both. The confusion of the two terms often makes us blind for the fact that it is primarily technology that forms the basis for the relevance of both. It is not science that we meet most often in society. Science is an activity that happens largely beyond what we observe as citizens. It rarely happens that a scientific discovery becomes headline news. What does get in the newspapers are the new technological devices that are brought onto the market or the problems that existing ones may suddenly appear to cause. For that reason one can question if the often used slogan 'science for all' in educational circles should not be replaced by 'technology for all'. Yet, there are good arguments also to claim that scientific literacy is important. One obvious reason is that a lot of modern technologies have been developed with intensive use of scientific theories. But there is another good reason. One could well claim that it is in our very human nature to be curious and to study the natural phenomena around us. For as long as written history exists, we know that humans have always tried to come up with explanations for what happened and that soon they started to make careful observations in order to develop such explanations. If this is in our very nature, then becoming scientifically literate is a necessary component of developing as a human being. The same can be said for technological literacy. For as long as we know what humans did, we find evidence that they have developed devices to adapt their natural environment. Therefore, becoming a technologically literate person has to do with who we are, in the same way as scientific literacy has to do with that. This is also mirrored in the value we ascribe to science and technology in current society, expressed, for instance, in the amount of money we invest in those domains.

What does that mean for the content of scientific and technological literacy? In my view, it means that scientific literacy in the first place means that we develop knowledge, skills and attitudes that refer to our human curiosity. Becoming scientifically literate means to have an attitude of curiosity through which we do not take for granted whatever we see around us but have an open mind and be easily surprised and dare to ask questions about what may seem obvious to others. Furthermore, we develop skills that enable us to follow up with activities that help us find explanations successfully. While doing that, a scientifically literate person can also draw from existing knowledge about the phenomena we study. Likewise, a technologically literate person dares to question existing solutions to practical problems and identify new problems. (S)he also has skills that enable her/him to come up with new solutions, thereby drawing from existing knowledge about working principles, material properties, strategies for design activities, etcetera. A person who is both scientifically and technologically literate also recognizes the connections between the two: we learn about phenomena by developing devices of which the functioning is based on those phenomena and we enhance this development process by using existing knowledge of such phenomena. Reasoning plays a vital role in all this. Here, again, we see a difference between science and technology. This difference is often ignored and leads to a lack of acknowledgment of the importance of the technology part. Science is largely based on cause-effect reasoning: when we do this, this will happen. Technology, however, is largely based on means-ends reasoning: when I need this, I look for that. In practice, the two types are often used in combination. When designing an experiment aimed at studying a phenomenon, a scientist will use means-ends reasoning to come up with an experimental setting that will produce the necessary output. While doing the experiment, (s)he will then use cause-effect reason to predict what will happen and evaluate the outcomes. Likewise, an engineer will use means-ends reasoning to design an artifact, and then use cause-effect reasoning to predict its behavior (in order to compare it with desired behavior).

Teaching for scientific and technological literacy

Having now seen the difference between scientific and technological literacy and the importance and content of both, we can now ask the question how to prepare citizens for these two types of literacy. Here, again, we find the technology side ignored often. Many people will immediately say that this is the task for science education, not realizing that there is often a separate school subject in place that could at least contribute to technological literacy, if not be the primary source of it. This subject has different names in different countries and also different degrees of success. In Germany, often the term “Arbeitslehre/Technik” is used, in the UK it is Design and Technology, and in most other countries it is Technology or the literal translation of that word in the national language (in French: Technologie, in Dutch: Techniek, etcetera). In most cases this school subject has its roots in some type of craft education, but in many countries it is now way beyond that. In this subject, pupils and students are made acquainted with the principles of all sorts of devices, machines and systems in the domains of construction, transportation, communication, biomedical applications and production, just to mention the most important ones. Of course, technological applications often feature in science education. An important difference with science education, though, is that in technology education, we get to see the exciting and challenging process that leads to the new device, rather than just using the device to show how certain scientific concepts and principles can explain the functioning of that device. In other words, the design process has a much more important place in technology education than in science education (except for specific examples of science education in which design does feature strongly, but my claim is that these are the exceptions rather than the rule).

So I claim that we have to take into account both science education and technology education if we want to discuss properly how to teach for scientific and technological literacy. So I will take my readers into both science education curricula and technology education curricula. For both I will ask the question to what extent they display recognition of the need to develop scientific and/or technological literacy. This recognition is not to be taken for granted a priori. It may well be that we find science education or technology education curricula that only aim at transferring a collection of existing bits and pieces of knowledge without really developing the literacy that is needed to make sense of this knowledge in the context of our current society. In the past, and as we will see perhaps still in the present, the main aim of these subjects was to provide the necessary pre-knowledge for taking up a higher education study in these domains. Becoming a scientifically and technologically literate person was not what these curricula aimed for. The whole idea of these two types of literacy is recent, relative to the existence in time of these subjects. In fact, we can observe that both science education and technology education are in a state of transition, mainly because of the concepts of these two types of literacy. So there is hardly any reason to blame anyone if we would find that both science and technology education may not yet be fully engaged in developing scientific and technological literacy. What we would like to know, though, is where we are now in that respect.

One more issue before we move to the curricula. How about MINT? Are there already curricula for integrated science, math, technology and engineering education? The answers is: 'yes' as far as primary education is concerned, but 'no' as far as secondary education is concerned. At primary level, though, we face the problem of most teachers not having a background in science or technology and therefore shying away from teaching about science or technology. In secondary education the situation is better due to the specialized science and technology teachers, but this specialization is the very reason that there are no integrated subjects yet. That does not mean that there are no examples of integrated projects. But these have not yet had such an impact that they have caused changes in curricula. At the end of the analysis I will give one example: the new school subjects Nature, Life and Technology and Research and Design in the Netherlands.

An international approach

One of the developments in education that we have seen happening in the past decades is an increase of international contacts. In the past, we used to think of education as something that is entirely determined by national interests and circumstances. But since education research has developed as an effort to develop insights into how science and technology is taught and learnt, we have begun to realize that although there is certainly a national or even local dimension in that, there are certainly insights that have broader implications and go beyond the borders of countries and continents. This has led to an increased number of international conferences of both researchers and practitioners in which insights are shared and communicated. It has also led to an increased number of scientific journals in which such insights are made available for an international audience. This does not mean that we can now look for international curricula or even international research agendas. This has been tried in the past and so far with no success. National and local constraints are still important and in that respect the assumed 'world as a global village' is still far from the current practice. This does not take away, however, that it makes sense to look at a variety of countries if we want to make claims about the extent to which science education and technology education really develop scientific and technological literacy, and to what extent this is still lip service.

Of course, the number of countries that can be involved in an effort like that is almost endless and the practical limitations in writing this chapter do not allow for including many countries. Hence, I have made a selection and chose those countries that have gone through important developments in the past decades and therefore can be assumed to have made deliberate choices in putting together their curricula for science education and technology education. I have selected the USA, England, Australia (New South Wales, Western Australia and Queensland) and New Zealand as sample countries for this chapter. I will complement the information from these countries with specific developments in the Netherlands, because I think these offer interesting clues of how scientific and technological literacy could be done justice to as aims in science and technology education. What I will do in the next section is to present surveys of the structure and content of the science education and technology education curricula in the countries (states) mentioned above. This will enable us to make judgments about the extent to which they reflect scientific and technological literacy as their possible aims.

Analysis of science and technology curricula in different countries

USA

In the USA, the educational situation is very complex because of the autonomy of the various states in determining the content of the curricula. But a recent development that aims at creating more coherence between what happens in the various states is the development of national Standards. This has been done for both Science and Technology. There is a difference between the two in that the Standards for Science Education are for the subject Science Education, while for technology, the Standards are for Technological Literacy, and the document that contains these

Standards states that the teaching of technological literacy is not confined to the subject Technology education, but can also happen in the context of Science Education. The unwritten story behind this is that this made the Standards for technology politically acceptable, as the subject Technology Education still by far does not have the same status as Science education has, whereas technological literacy is generally seen as something very important (hence, too important to be confined to Technology Education). Let us now take a look at the two sets of Standards and see to what extent they contain elements of scientific and technological literacy. Chapter 6 of the Standards documents for Science contains the scientific content of the subject. The standards are subdivided into:

- Science as inquiry
- Physical science
- Life science
- Earth and space science
- Science and technology
- Science in personal and social perspectives
- History and nature of science

Sub-sets of Standards are defined for levels K-4 (primary education), 5-8 (junior high school) and 9-12 (senior high school). In addition to the many specific topics mentioned in these standards, some unifying concepts and processes have been defined:

- Systems, order and organization
- Evidence, models and explanation
- Constancy, change and measurement
- Evolution and equilibrium
- Form and function

What strikes us in the subdivision of standards is that only the first and the last category are about the nature of science and the others are subdomains in science. A closer inspection of the content reveals that these other categories are largely filled with getting to know existing knowledge in these subdomains. Although experimentation does feature in the standards, we get the impression that the purpose of that is primarily to come to the existing knowledge, whereby surprises are not to be expected. What strikes in the unifying concepts and processes is that this existing knowledge is now ordered in a way that aims much more at understanding and fundamental insight than is the case in existing science education curricula. In that respect the new standards are definitely a step forward compared to existing curricula. Although at first sight the concepts seem to be different from what Osborne et al. (2003) identified as important concepts in a recent Delphi study, they do overlap to a large extent. Let us now move to the Standards for Technological Literacy. Five domains of Standards are described, each with some subdomains:

- Students will develop an understanding of the Nature of technology
  - Characteristics and scope of technology
  - Core concepts of technology
  - Relations with other fields
- Students will develop an understanding of Technology and society
  - Cultural, social, economic and political effects
  - Effects on the environment
  - Role of society in the development of technology
  - Influence of technology on history
- Students will develop an understanding of Design
  - Attributes of design
  - Engineering design
  - Troubleshooting, R&D, invention, innovation, experimentation
- Students will develop Abilities for a Technological World
  - Apply the design process
  - Use and maintain products and systems
  - Assess the impact of products and systems
- Students will develop an understanding of The designed World
  - Medical technologies
  - Agricultural and biotechnologies
  - Energy and power technologies
  - Information and communication technologies
  - Transportation technologies
  - Manufacturing technologies
  - Construction technologies

Here we are struck by the fact that subdomains of engineering are the minority category, whereas in the science standards subdomains of science were the majority. The technology standards seem to have a stronger focus on the nature of technology, its social impacts and the process of developing new artifacts and systems rather than learning about existing artifacts and systems (which would be the equivalent of what happens in the science standards). Here surprises are possible, depending on how seriously the teachers take these standards and allow pupils and students to really come up with novel designs.

England and Wales

In England and Wales there is a national curriculum that is described for four Key stages. Key stage 1 is the first three years and Key stage 2 is the last three years of primary education, Key stage 3 is the first three years and Key stage 4 is the last three years of secondary education. For both science and technology there are curriculum descriptions for all four Key stages (which do not mean that these subjects are compulsory for all Key stages). For Science, the attainment targets are grouped in four domains:

- Scientific inquiry
- Life processes and living things
- Materials and their properties
- Physical processes

It seems that here, too, we have an emphasis on subdomains of science (in this case fairly directly related to biology, chemistry and physics) rather than on doing research that may lead to new explanations for everyday life phenomena, as one would expect for scientific literacy.

The curriculum for Design and Technology has a similar structure. Domains are:

- Developing, planning and communicating ideas
- Working with tools, equipment, materials and components
- Evaluating processes and products
- Knowledge and understanding of materials and components
- Knowledge and understanding of systems and control (Key stages 3 and 4 only)

Compared to the Science document there is much more emphasis on the process aspects of the discipline, just like in the USA case. In Science only one domain focuses on the process of science, while for technology three out of five domains have this focus. The basic and overarching concepts identified by Rossouw et al. (2011) can be found throughout the document, even though we do not find them in the chapter tiles as prominently as in the USA case. In that respect the document does reflect the way technologists think and stimulates technological literacy. What seems to be absent, though very important from the point of view of technological literacy, is the users' point of view. The curriculum primarily takes the stance of the designer/engineer, not of the citizen who is confronted with the outcomes of technology and has to respond to that.

Australia

The educational context of Australia is very similar to that in the USA: there are states that have a large degree of autonomy over the content of the curriculum. As a full description of the science and technology curriculum in all six states (not even considering the territories outside the mainland) would be impossible within the limitations of this chapter, I have chosen New South Wales, Queensland and Western Australia as they have been the most active states in the development of teacher training and research for technology education, the original primary focus of this chapter.

In New South Wales Science and Technology have a combined syllabus for primary education, as in many other countries. Learning outcomes have been organised in the following groupings:

- Knowledge of built environment, information and communication, living things, physical phenomena, products and services, earth and its surroundings, investigating, designing and making, and using technology.
- Skills in investigating, designing and making, and using technology
- Values and attitudes towards the learners themselves, towards others, and towards science and technology

For Queensland we have separate description of Essential Learnings for Science and Technology for all grade levels. They are grouped in: end of Year 3, 5, 7 and 9. For Science domains are: Ways of working (with ten activities students must be able to) and Knowledge and understanding (with subdomains: science as a human endeavour, earth and beyond, energy and change, life and living, natural and processed materials). For Technology the same main domains are defined and the subdomains for Knowledge and understanding are: technology as a human endeavour and information, materials and systems (resources).

In Western Australia we also have separate description for the Learning Areas Science and Technology/Enterprise in the Curriculum Framework for all school levels. For Science two domains are defined: working scientifically (subdomains: investigating, communicating, daily life, acting responsibly, science in society), and understanding concepts (subdomains: earth and beyond, energy and change, life and living, and natural and processed materials; almost the same as the ones in Queensland). For Technology/Enterprise we find the domains technology process, materials, information, systems, enterprise, technology skills, and technology and society.

Of these three states, New South Wales has the curriculum that has the strongest suggestion of scientific literacy elements in that it acknowledges the importance of not only knowledge but also skills and attitudes. The other two states seem to have more traditional science education curricula in which the subdomains of science feature strongly. For technology, we see the same tendency as in the countries described earlier, namely that there is more emphasis on the process of technology than on learning about specific devices. The citizen point of view does not feature very prominently, although the term ‘technology and society’ suggests some attention for that.

France

In France, science and technology are one subject in primary education. The curriculum used to look pretty traditional and as in many other countries, primary school teachers had difficulties coping with it, given their lack of background in science and technology. In 1996, an interesting project was launched and introduced in schools: “La main à la pâte” (which translated into something like: “Let’s get to work”). It was initiated by the Académie des sciences (Georges Charpak, Pierre Léna and Yves Quéré) and the Institut National de Recherche Pédagogiques. It is based on vary open-ended observation of phenomena by children and cooperation with university staff is mentioned as one of the principles of the project. The projects have been received very positively, not only in France but also internationally. As for secondary education (called “Collège in France, not to be confused with the English word “College”), the curriculum for science (“Physique-chimie”) and that for technology (“Technologie”) have a common introductory part in which four elements have been defined:

- the “scientific and technological culture”
- basic knowledge and skills (such as some math and basic scientific notions)
- research skills
- the use of information technologies
- unifying themes:
  - statistical thinking
  - sustainable development
  - energy
  - meteorology and climate
  - health
  - safety
  - use of foreign languages

It is remarkable that we find some of the contexts identified by Rossouw, Hacker and De Vries here that were rather rare in the curriculum in other countries (sustainability, safety). Then follow the parts that are specific for Physics-chemistry and for Technology. Again we see the same difference that we have also seen in other countries: the physics-chemistry goals are described in terms of phenomena to be studied and the technology goals are formulated in terms of the process of engineering.

New Zealand

Let us now look at the New Zealand curriculum for science and technology. The Science curriculum has five domains:

- Nature of science (subdomains: Understanding about science, Investigating in science, Communicating in science and Participating and contributing)
- Living world (subdomains: Life processes, Ecology and Evolution)
- Planet earth and beyond (subdomains: Earth systems, Interacting systems and Astronomical systems)
- Physical world (subdomains: Physical inquiry and physics concepts, Physical concepts and Using physics)
- Material world (subdomains: Properties and changes of matter, The structure of matter and Chemistry and society).

This seems to be not very different from what we have seen in other countries: the emphasis is on what is known already in the domain of science; concepts that are characteristics for the work of real scientists are used; investigating is an often used term that refers to the way scientists work and pupils have to do that in order to find what the scientists have already found in the past; the work of scientists today is not really referred to. Now for technology. Here we find three domains:

- Technological practice (subdomains: Planning for practice, Brief development, and Outcome development and evaluation)
- Technological knowledge (subdomains: Technological modeling, and Technological products, Technological systems)
- Nature of technology (subdomains: Characteristics of technology and Characteristics of technological outcomes).

Here, too, we find elements of the usual pattern: the emphasis is on what technologists do and not on the outcomes of technology (knowledge about the vast number of artifacts around us) and key concepts for the field are used and compared to curricula in other countries, These concepts are remarkably well thought over as they have clearly been derived from literature in the philosophy of technology, more so than in other countries. Again we see the absence of the user/citizen perspective.

The Netherlands

Having been relatively short about France, I want to spend some more words on the Netherlands, because of some interesting developments in that country. In the Netherlands, the curriculum for primary education (eight grades, including two for Kindergarten) and for the first three grades of secondary education are described in a short list of goals. For the further grades (the number of those is different for different types of schools) there is an exam syllabus. In the Netherlands there is a fairly strong textbook culture in secondary education, so that what schools do depends largely on which schoolbook the teacher has chosen. For both science and technology education there are at least 5-6 competing titles. For primary education the goals for science and technology are formulated as follows (available online in Dutch only):

- Children learn to identify common plants and animals in their environment, know their names and how they function in their environment
- Children learn about the structure of plants, animals and humans and the form and function of their parts
- Children do research on materials and physical phenomena such as light, sound, electricity, force, magnetism and temperature
- Children learn how weather and climate can be described by means of temperature, precipitation and wind
- Children learn to see relations between functioning, form and use of materials in daily-life products
- Children learn to design solutions for technological problems, construct those and evaluate them
- Children learn that the position of the earth in relation to the sun causes seasons and days and nights

Most primary teachers shy away from all science and technology activities because of lack of background in these fields. This is probably the case also in several of the other countries that we have seen. It relativises all the nice documents that we have seen so far. Only when a substantial effort is made to provide in-service training to these teachers it can be expected that science and technology activities are implemented and even then the step of making contacts with scientists and technologists is a drastic one for the teachers.

For secondary education the situation is different. The Netherlands traditionally is one of the forerunners in developing new approaches to science education. In technology education it was a late-comer but was able to catch up quickly by combining different approaches found elsewhere. For the first three grades the following goals have been formulated (available online in Dutch only):

- Pupils learn to transform questions related to scientific, technological and care-related issues into research questions, to carry out a decent research on a scientific topic and to present the outcomes of it
- Pupils learn to acquire knowledge about and insight into key concepts related to living and non-living nature and connect those to daily-life situations
- Pupils learn that humans, animals and plants are in interaction with each other and their environment and that technological and scientific applications can influence the sustainable quality of that in both a positive and a negative way
- Pupils learn to acquire knowledge about and insight into processes in the living and non-living nature and their relation with the environment by doing practical work
- Pupils learn to work with theories and models by researching physical and chemical phenomena such as electricity, sound, light, motion, energy and matter
- Pupils learn to acquire knowledge about technological products and systems that are relevant for him, to appreciate this knowledge and to design and make a technological product in a methodical way
- Pupils learn to see the basic issues related to construction and function of the human body, identify relations with and advance physical and psychical health and take a personal responsibility in that
- Pupils learn about care and learn to care for themselves and their environment, and how to influence their own safety and that of others in different living conditions (housing, learning, working, leisure, traffic) in a positive way.

In 2012 a new syllabus will be introduced for all physics, chemistry and biology that is much more based on practical contexts. It builds upon the concept-context approach in which concepts are taught and learnt in a variety of contexts (Bulte/Westbroek/De Jong/Pilot 2006). The new programs contain several explicit references to practical contexts, although the domains are still divided according to disciplinary subdomains (mechanics, electricity and magnetics, etcetera) and for physics and biology no mention is made of industry. ‘Technology’ is a separate sub-domain in the new syllabi as is ‘research and design’. In the description of this last sub-domain reference is made to the contexts mentioned in the other subdomains. In itself attention for contexts does not necessarily mean that real inquiry is stimulated. After the implementation of this new syllabus, we will have to see how this will be put into practice. At least it will mean that the practical relevance of science will become clearer to pupils, which certainly contributes to scientific literacy.

Another interesting development in the Netherlands is the new subject “Nature, Life and Technology”. Modules for this subject are developed in a cooperation between schools, universities and industrial companies. This means that teachers have direct contact with the practice of science and technology and the results of those contacts are visible in the course material. A certification procedure is in place to assure quality. Examples of topics of modules that have been certified so far are: Drinking water purification, artificial kidneys, Sound design, Holography, CO^2-storage, Robotics, Biomedical design, Medicines, The mp3-player, and Forensic research. There are currently about 40 certificated modules available for schools. The modules are often taught in teams of physics, chemistry and biology teachers. The subject is not compulsory, but gains rapidly in popularity among pupils. A number of secondary schools in the country has the status of Technasium, which means that they have a subject called "Research and Design". The status of Technasium can only be awarded by the Technasium Foundation and they require that this subject is executed always in cooperation with industries and universities (they provide realistic problems and co-supervise the pupils when solving these). The subjects NLT and Research and Design seem promising in terms of offering opportunities for realistic investigations and design activities that contribute to scientific and technological literacy. The subjects connect pupils to the real worlds of science and technology by making them cooperate with researchers and engineers. There are no official evaluations of these courses available yet, but rumours are positive. Both teachers and pupils seem to enjoy the courses and learn from them. In the coming years hopefully sound evaluations will show that this is the case indeed.

Conclusions

Let us now summarize what we have found. Science education curriculum documents today contain inquiry-based learning. Pupils and students ought to make their own inquiries to investigate phenomena. Of course we can not tell from these documents to what extent that happens in practice, but that is a limitation inherent to the research method I have chosen. What is also not so clear is whether or not this inquiry leaves space for surprise. Does it mean that pupils can study phenomena present in, for instance, toys that do s thing, which the teacher does not immediately understand? Or is the inquiry aimed at finding the knowledge that in the end appears to be in the textbook already? In my view, the reality of the search (because the teacher also does not yet offer the explanation) makes it much more exciting and would very much contribute to the – now often lacking – popularity of science education. Furthermore, the curriculum documents suggest that most of the time is still spent on transferring the already existing body of scientific knowledge. Exam syllabi are filled with that and teachers feel obliged to prepare pupils for that as good as they can. Real inquiry-based learning costs a lot of time and probably teachers will hesitate to spend that because the urgency of the exam syllabus will be felt strongly. In other words: science education curricula focus on the existing body of knowledge and real inquiry takes a modest position only. So science education curricula only moderately aim at scientific literacy. The role of technology in science education is also modest. Although examples of technological applications do feature in the curricula, they seem to be used only either as a motivation to learn science ("would you like to know how this works?") or as an illustration afterwards ("we will now see how this principle has been applied in a device that you all know"). Pupils do not get to see how and when this knowledge played a role in the design process, and neither do they get to see what knowledge from other than natural sciences was used. So the contribution of science education to technological literacy is also modest at best.

Is this different for technology education? In some respects it is. The technology education curriculum documents put much more emphasis on the process of technology than the science education curricula do for the process of science. In particular design takes an important place in the curricula, and from practice we know that many teachers follow this direction. We also know that the popularity of technology education with pupils is often due to the fact that many teachers do allow real surprises. Real inventions are made, though not, of course, at professional level. Also many examples are available of projects that were done in cooperation with real professionals in industries. In this respect, technology education is often closer to the real world of technology than science education is to the real world of science. Many science education curricula do not even mention the word 'scientist', nor is their any explicit incentive to do inquiry in cooperation with real scientists. What lacks, though, in the technology education curricula is the user (or citizen) perspective. Critical dealing with technology, critical choices in what we buy and how we use it, are not found prominently in the technology education curricula. That means that technology education curricula, too, have their biases in addressing technological literacy. Also striking is the absence of science knowledge in most technology education curricula. Technology education seems not to contribute to scientific literacy in any meaningful way.

As was remarked already in the beginning, national standards and syllabi still keep the MINT components separate. Successful examples will be needed to stimulate integrated curricula. For this, there will always be the problem that connections between these components cannot always be made evident at school level. Most technologies that were developed largely on the basis of scientific knowledge are fairly sophisticated and both the science and the technology knowledge needed to understand those go beyond school level. In my view, the most promising way is to show that varying a design systematically and thus getting to know the physical, chemical and/or biological variables that make a difference for the functioning of the design connects scientific research and technological development in a natural way. But that suggests that all scientific research is for the sake of improving designs and this is not the case. This research and development approach must therefore be complemented by a different approach that is based on pure curiosity and the desire to explain phenomena that intrigue us, even when we cannot yet foresee any practical application of that (which is anyway not our primary motivation in that case). So even in a MINT curriculum there should be room for the separate components to be done justice to.

The whole picture suggests that we still have a way to go if we want science education and technology education really to contribute to a scientifically and technologically literate citizenship. There are still major gaps in the science education and technology education curricula in that respect. Further steps need to be taken. The education initiatives of the Berlin-Brandenburgische Akademie der Wissenschaften certainly have the potential of contributing to that.

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