Chapter 4
Students' Use of Science and Mathematics in Practical Projects in Design and Technology

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4.1 Introduction

The knowledge component of technology in the school curriculum remains a contested terrain (see, e.g. Jones et al. 2013). On one hand, technology can be seen as representing a domain of knowledge in itself, while on the other hand technology as a field of activity makes use of and combines knowledge from a range of different areas in order to fulfil specific purposes. In particular, modern technology makes high use of scientific knowledge in its development. This ambiguity is reflected in the challenges represented in defining technology as a school subject worldwide.

The curriculum for compulsory school in Norway places *technology and design* as a cross-curricular field involving the subjects science, mathematics and art and crafts. This chapter presents a classroom video study of practical projects in technology and design developed in line with the curriculum, where we investigate the knowledge content of science and mathematics manifested in the projects in terms of students' actions and teacher-student dialogues. The analysis is done in light of the intention of the curriculum, and the study hence provides an examination of the epistemic foundation the curriculum is built on.

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4.2 Perspectives on Technological Knowledge

In the philosophy of technology, many attempts to capture the nature of technological knowledge have been made, from a philosophical point of view as well as from an educational perspective (see, e.g. Layton 1991; McCormick 1997; Staudenmaier 1985). One reason why technological knowledge is so hard to conceptualise is that technology is highly situated in the practical context and involves knowledge that cannot be understood simply by means of discerning the relevant scientific laws (Boon 2006). To be useful, this knowledge needs to be reconstructed, combined with other forms of knowledge and adjusted to the situation at hand (Layton 1991). The reconstruction often entails that the level of abstraction is reduced but the complexity increased.

This is in line with how Staudenmaier (1985) has provided characteristics of technology as a domain of knowledge, based on his thorough analysis of what constitutes technological knowledge in various domains of the field. He described technological knowledge as combinations of scientific concepts, engineering theory, problematic data and technical skills. This conception of technological knowledge illustrates that even if technology is deeply situated in practical contexts, it also comprises knowledge that is theoretical and generic in nature. Some components of this theoretical knowledge stem from science, while the category engineering theory is theoretical knowledge that is purely technological in nature.

This means that technology is much more than the direct application of pure scientific knowledge. However, science and technology are highly interrelated in their modern form: modern technology builds to a high degree on advanced scientific knowledge, and the advancement of science is in turn highly dependent on technology. Modern science and technology are hence described as a 'seamless web' (Hughes 1986).

Despite this development, science and technology are still seen as different domains of knowledge and activity, and their different *purposes* are often used to make a demarcation between the two areas of knowledge and activity (see, e.g. Ropohl 1997). While the purpose of science is to establish generic knowledge that covers as many contexts and situations as possible with explanatory power, the aim of technology is to develop products and systems with a specific purpose and function. This difference in purpose gives rise to differences in what is seen as progress in the field and what is considered valuable knowledge: progress in science is models that better explain the world while progress in technology is more efficient solutions.

4.3 Representation of Technology in General Education

In education, different perspectives on what technology and technological knowledge mean provide for different positioning of the knowledge domain in the school curriculum. The main challenge is to conceptualise the identity of the subject, its disciplinary content and relationship to other subjects (Jones et al. 2013).

In school science, technological applications have often been presented as part of the science curriculum, not necessarily with a perspective on knowledge but rather in order to make the science content more concrete for the learner and to demonstrate its relevance in society and everyday life. These approaches have been massively criticised as they tend to portray technology as straightforward applications of science and hence do not do justice neither to technology nor to science (e.g. Boon 2006; de Vries 1996; Gardner 1994; Layton 1991).

Other traditions of technology education place the domain within craft and vocational training, often associated with less able students and with a low social status (see, e.g. Hansen 1997). In recent decades, however, technology has emerged as a subject in its own right and for all students in several countries. The subject has been modernised and broadened to include design and notions of technological literacy (Jones, et al. 2013).

While technology as a subject for all students makes technology more visible in the curriculum, many have pointed to that the close relationship that exists between science and technology should be represented in how students engage with science and technology in their general education (e.g. Barlex and Pitt 2000; Bencze 2001; Petrina 1998; Sidawi 2007). Also for mathematics teaching, studies have pointed to the potential for integration with technology (e.g. Norton and Ritchie 2009). Technology is seen as providing rich contexts for learning and applying mathematics in authentic and relevant contexts, as well as developing more positive attitudes towards the subject.

A curriculum organisation in line with this view was introduced in the current curriculum for Norwegian compulsory school in 2006 (The Norwegian Directorate for Education and Training 2006). The topic *technology and design* is placed across the subjects science, mathematics and art and crafts, with the intention that practical projects in technology and design will provide meaningful and motivating contexts for learning and applying science and mathematics. This explains why mathematics is seen as part of the domain of technology, while, for example, social science is not, despite the importance of technology in human history and in development of society.

Investigations into the implementation of the subject area in schools indicate that even if teachers are positive to technology and design in the curriculum, it gets relatively little attention and teaching time, partly due to practical and organisational reasons (see Dundas 2011).

4.4 A Video Study in Schools: Research Focus and Methods

The study presented in this chapter attempted to support teachers in developing effective and motivating student projects, as well as investigating how conceptual knowledge from science and mathematics come into play when students work with projects in technology and design. Conceptual knowledge is taken to denote declarative, generic knowledge comprising concepts, relationships and principles that may have significance for action (see McCormick 1997). The study is undertaken by analysing how students deal with and communicate knowledge and activities in cross-curricular student projects in technology and design developed and implemented in three different Norwegian schools (year 3–10).

In the research project, six student projects were developed in cooperation with the local teachers at six different schools (see Bungum et al. 2014). In the development, we attempted to create cross-curricular projects with a good potential for incorporating science and mathematics, but also attended to that the projects should be realistic to run in schools with regard to materials as well as teacher knowledge and skills. Analysis of teacher-student dialogues in these six student projects revealed that science and mathematics were virtually absent from dialogues between teachers and students, despite the fact that the projects were designed with the purpose of including these subjects in meaningful ways. The conceptual knowledge addressed by teachers during the technology and design projects was for the most part technological in nature.

In the present study, we investigate the issue further by analysing the material with focus on *why* knowledge from science and mathematics is not addressed to a higher degree in the students' projects. We investigated video material from three of the student projects from the original study. The projects chosen for the deeper analysis were those anticipated to contain most content knowledge from science and/or mathematics. Each project lasted ca 30 h. Members of the research group were present in the classrooms in a substantial part of the project period, but influenced teachers' and students' work to a very limited degree.

Classroom sessions related to the project were videotaped with three cameras recording two selected groups of students and the classroom as a whole, respectively. A fourth camera was used to record other situations of interest that occurred in the classroom. In addition, the main teacher was carrying a wireless microphone throughout the entire project in order to record all teacher-student interactions.

In the earlier study, all dialogues between the teacher and students have been analysed quantitatively with regard to the kind of knowledge represented in the conversation (see Bungum et al. 2014). In the present study, we have analysed selected episodes with regard to why knowledge from science and mathematics is *not* represented in situations considered to have a potential for this. This analysis is interpretative and broader in the sense that it considers not only dialogues but also students' actions in the project and the objects they produce.

Sequences of the video material were purposely selected as they provided illustrative examples of situations where the potential for science and mathematics content was not fulfilled. This selected material was reduced to four episodes that illustrated different aspects of the phenomenon under consideration. From these, we formulated four issues (categories) that have been refined and adjusted through consideration of the video material as a whole and through observer triangulation between members of the research group in interpreting sequences of video data. These categories are presented as results of the study, illustrated by the episode that gave rise to each category.

According to Merriam (1998), categories resulting from inductive analysis should be exhaustive, mutually exclusive, sensitising and conceptually congruent as well as reflecting the purpose of the research in the sense that they provide answers to the research question. The categories developed in this study provide broad answers to the question of why knowledge from science and mathematics is not represented in the student projects. As this concerns an *absence* of something, the formation of categories is inevitably exploratory. The categories are informed by, but not derived from, the theoretical perspectives on technology described in the foregoing. They are mutually exclusive in the sense that they conceptualise distinct issues, but not necessarily exclusive with regard to episodes in the material. This means that events in a project sequence might fit in more than one category. Still, the categories highlight different aspects of why conceptual knowledge in science and mathematics does not come into play when students work with a project on technology and design.

4.5 The Student Projects

The three student projects in this study were as follows:

4.5.1 Models of Playground Equipment

In this project, students in grade 8 designed models of playground equipment by means of the software Google SketchUp and built the models in cardboard and other materials. The software facilitates the making of templates of the individual parts of the construction with accurate measures. Conceptual knowledge from mathematics is involved by the scales students work with in order for the measures to be suitable for the purpose. It could also involve basic mechanics in how the equipment works (Fig. 4.1).

Fig. 4.1 Model of playground equipment

4.5.2 Model of Town with Lights

The project involved building a model of the students' hometown Hammerfest, with streets and buildings and surrounding landscapes including mountains and a fjord. The project was undertaken in a class of grade 10, where students worked in groups performing various parts of a joint model. Students themselves were to decide on what scales to use and what parts of the city and the landscapes that were to be represented in the model. The model was to be enlightened by electric light, making a link to the fact that Hammerfest was the first town in Norway with electric street lights. The project has potential for working with conceptual knowledge in terms of scales in mathematics and principles of electric circuits in science (Figs. 4.2 and 4.3).

Fig. 4.2 Town model

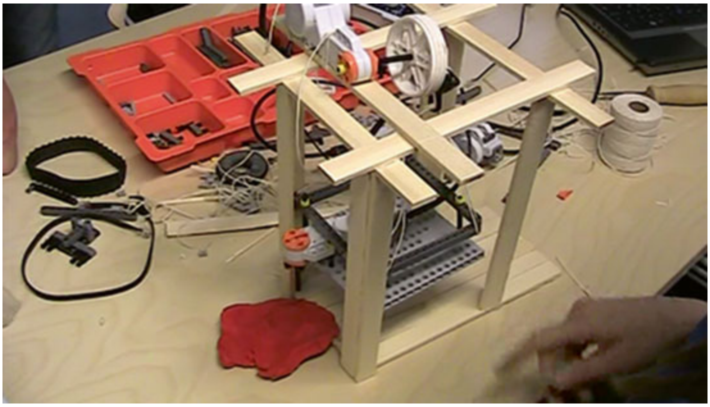

Fig. 4.3 Model of oil drilling system

4.5.3 Model of Oil Rig and Drilling System

The activity was undertaken in grade 8 and formed part of a larger project about oil exploration. Students used Lego Robotics to construct the drill and were allowed to use various materials for making the platform. The main challenge for the students was to design a motor system that allowed the drill to rotate and simultaneously make a vertical movement. The project potentially involves concepts and principles from mechanics, such as force, energy and transformation of movement.

4.6 Results and Analysis: *Why* Is Science and Mathematics Absent from the Design and Technology Projects?

From the data from the three described projects, we have identified four key issues of importance for why the design and technology projects, as they were realised in schools, did not contain any significant component of knowledge from science and mathematics, despite the fact that they were partly designed to do so. The four issues are conceptualised as (1) problem solving by other means, (2) focus on product quality, (3) task requires specialised knowledge and (4) concepts and principles not necessary for the purpose.

In the following these issues are described by means of episodes from the video material. The subsequent discussion relates the findings to how the nature of technology and technological knowledge is described in the literature and then discusses implications in an educational context.

4.6.1 Problem Solving by Other Means

In the projects, students encountered challenges that potentially could invite them to make use of knowledge from science and mathematics to solve the problems and develop their products or to generate a need for attaining this kind of knowledge. The use of scales in making models is an example from several of the projects analysed. The selected episode is from project 2 where students design a model of their hometown and surrounding landscape and where correct scales were essential in order to make different parts of the model fit each other. The project is good in this regard, as correct use of scales is a prerequisite for success, and the challenge is placed in a very concrete context. The task became, however, rather complex due to the irregular shape of the landscape the students were to model and also because students had to move between three representations when calculating scales: the model, the map and the real landscape.

This sequence shows how students arrive at a way of solving the problem of scaling up parts of the map to fit the board where the town model is to be built. The students are discussing and calculating, standing beside the map hanging on the wall:

Student 1: But how on earth can we get this thing onto the board?
Student 2: We just measure in centimetres…
Student 3: What we do is to get this [the map] onto an overhead foil. Then we put the board up towards the wall and move the overhead projector backwards until it fits. And then we just transfer the drawing!

The group of students enters the task with renewed enthusiasm and solves the problem in much more effective and reliable ways than by using scales to calculate measures for each parts of the model. For mathematics content, the student's solution involves understanding of scales in the sense that she was aware of how an overhead projector creates an enlarged image with identical geometry as the original map. Other students might also learn from this experience. However, in the end it did not give the student group as a whole much experience in calculating scales the way they learn, and are tested, in mathematics as a school subject.

4.6.2 Focus on Product Quality

In technology and design, the quality of the final products is more pertinent than in the practical work students usually perform in science and mathematics. The desire for high quality influences the choices teachers and students make and hence the knowledge involved in the activity. In some instances, this means that a considerable amount of time is spent in enhancing the quality in terms of various forms of decoration, which may diminish the focus on technical problem solving. In the projects in this study, we also found examples of how desires for product quality diminished the focus on knowledge components from science and mathematics in other ways.

The selected episode is from student project 2, supposed to entail working with electric circuits, and hence elements from the science curriculum. This could have been done by giving students experience with wiring lights and thereby working with principles such as closed circuits and differences between circuits in series and parallel. Instead, the teacher provided chains of ready-made Christmas lights for lighting up the town model. This makes perfectly sense from a pragmatic point of view, as the light chains are easily available, relatively cheap and make the resulting product of higher quality than letting students wire their own circuits, which would be more time-consuming and probably result in unstable circuits. At the same time, this choice diminished the science component of the project, as there was no need for experimenting with or discussing properties of the electric circuit. The project on creating the town model involved, however, other motivating challenges for the students, and the teacher described the students' learning as 'high-level problem solving' in a heuristic way rather than in terms of specific content outcome from subjects in the curriculum.

4.6.3 Task Requires Specialised Knowledge

In some aspects of the student projects, challenges for students require understanding of general principles in order to accomplish their tasks. The episode selected represents the model of an oil rig students are to construct with Lego systems in project 3. The Lego set contains a great variety of components to be combined in order to construct the desired mechanism. The working principles of the components and their combination can in principle be described by means of concepts from physics, such as rotation, velocity, force and energy transfer. None of these concepts were used by students or the teacher in any scientific way in the project. This is with good reason, since the mechanisms are better described in terms of principles that are technological in nature, more specialised and directly related to the components students are working with. The video recordings of the project revealed that students did not possess this kind of knowledge and that this obstructed their progress in the project. Their work to make the desired mechanisms was hence characterised by trial and error with the available components and heavy guidance by the teacher in order to arrive at the desired movement in the model of an oil rig. The teacher's guidance of one group of students who was to construct a device that can transform rotation into vertical movement involved the following sequence:

Teacher: The point is, how can you make this motor lift this other one? Have you seen this piece? [The teachers show the group of students the Lego brick that works as a rack.]

Student 1: I know it.

Teacher: Yes, is it possible to use this one? (…) Let's say, a cog is assembled to this shaft, for instance… [The teacher puts a shaft in the centre hole of the motor and mounts a cog to the shaft]. The cog will rotate, ok?

Student 2: Yes.

Teacher: So, if you then could mount this part [the rack] perhaps like this [joins the rack and the cog]… do you agree that this [the rack] will move up and down?

Student 3: Wow, that was smart!

The teacher puts the students on the right track by showing them how mechanisms can be used in order to achieve the desired result. The guidance is very visual, demonstrating the teacher's 'know-how' in the particular situation. The use of language is hence limited in terms of concepts. However, the relevant concepts (such as those added in brackets above) are specific technical concepts rather than scientific concepts for how the suggested devices for the mechanism work. The concepts learnt in science can be related to the task, but are too general to be of any practical use.

4.6.4 Concepts and Procedures Not Necessary for the Purpose

In some parts of the student projects, teachers attempted to include concepts and principles from science and mathematics, in line with the intentions of the curriculum. This was not always well received by students, as they did not see it necessary for solving the technology and design task they were working on. They were highly motivated for the practical project, but this did not necessarily motivate them for using the project as context for working with science and mathematics as the task could well be solved with less advanced knowledge that the student already possessed. Our illustrating episode is a situation where a student has used Google SketchUp to construct a model for a playground construction (project 1). This student usually showed low motivation for traditional school subjects and particularly for mathematics. However, in this project he had worked with strong dedication on designing the playground construction on the computer. The teacher saw this as a good opportunity to get the student involved in calculations of scales for his model. Some of the dialogue ran as follows:

Teacher: With this scale, this side becomes 32.42 cm. Is that an appropriate measure for your model?
Student: I *said* it is to be 30 cm!
Student: This side is to be 15 cm.
Teacher: But that is not in accordance with your drawing.
Student: (annoyed) So what?!
Teacher: We have now found two of the sides. Now you can do the rest. You will manage
(student showing reluctance).
Teacher: You don't seem to agree?
Student: I don't know, I cannot do math, I hate math!

Not only is this student reluctant to dealing with mathematics as such, he clearly also doesn't see it as bringing him any further in the practical task of constructing the model. Actually, he is perfectly right in that his rough measure of '30 cm' is sufficient for the purpose and doesn't need to be further specified by the precise measure resulting from calculation the teacher tries to make him do. In addition, even if the teacher is patient and does an effort to get him involved, the student seems to lose his motivation for the project that he initially enjoyed working with.

4.7 Discussion: Relating Findings to Perspectives on Technology

Our empirical study and analysis have identified key issues of importance for why conceptual knowledge from science and mathematics does not necessarily form part of students' work in design and technology, even if the subject matter from these subjects seems relevant for the task.

The issue *Problem solving by other means* reflects the nature of technology in the sense that the activity is flexible in use of ideas and materials. Technological activity searches for usable solutions that are optimal in terms of labour, costs and result. When students overcome the problems of calculating scales by utilising an existing technology (the overhead projector) that is more effective and probably more reliable, it resembles to a high degree the way technologists work. The students have many times watched teachers moving projectors back and forth in order to adjust the size of the image it creates. This associative way of solving the problem by imagining how tools can be transferred from one context to another can be seen as an example of technological creativity (see Lewis 2009). From a mathematical point of view, the students' solution clearly involves mathematical thinking, but it does not provide any experience with the kind of calculations students are expected to perform in mathematics and required in the curriculum.

Problem solving by other means based on student initiative is relatively rare in the data material, and this can be explained by the fact that students often lack knowledge about and access to the more effective alternative means. Teachers might also actively restrict students' access to alternative means for the sake of including the basic skills, such as calculating scales by hand, that might form a learning target in the activity. If the aim is to foster technological capability, however, teachers should encourage the alternative technology-based approaches and equip students with knowledge of the relevant effective technological tools prior to the project.

The second category *Focus on product quality* relates to the previous in the way it reflects the nature of technology. The difference lies in that problem solving by other means concerns the work process, while this issue concerns the resulting product. When designing and making a product, students and teachers will value the result of high quality. The industrial designed light chains in project 2 are clearly of higher quality than self-soldered circuits, in terms of aesthetics as well as reliability. McCormick and Davidson (1996) have pointed to what they denote the 'tyranny of product outcome' in design and technology classrooms. They argue that the focus on the final product prevents students from going deeply into the design process. From our study, we can conclude that this also applies to the potential science learning outcome of the activity. Again, the way the teacher and students approached the task of enlightening their town model makes perfectly sense from a technological point of view. In order to integrate content knowledge on electric circuits in the project, the task would need to be more complex, for example, by creating a desire to enlighten all the smaller roads in the town model, where ready-made light chains no longer are suitable. This could alter the conception of what product quality means in the project.

Task requires specialised knowledge involves that the knowledge that potentially could be related to the technological activity is not of an appropriate character for the purpose. The task requires more specialised knowledge that school science offers. In this study, this applies in the project about drilling rigs. Mechanisms for transfer of movement are associated with concepts and principles, but these do not mainly involve the basic concepts of physics. Rather they represent operational principles (Vincenti 1990) and engineering theory (Staudenmaier 1985) more appropriate for this technological domain of knowledge. As Layton (1991) has pointed to, scientific knowledge of physical mechanics is not directly applicable in this context and will have to be restructured according to the specific mechanisms in order to be useful. The problem for students in designing the model of the drill was clearly related to their lack of familiarity with mechanisms and their principles. The problem would not be solved by concepts from physics, but rather by genuine technological knowledge of the various mechanisms' operational principles.

The fourth category, *Concepts and procedures not necessary for the purpose*, relates to how content from science and mathematics is seemingly relevant in the context, but where it does not contribute to the students' activity in the sense of generating a product outcome. The student used as example from the project on constructing models of playground equipment expresses this in very explicit terms, as he refuses to deal with mathematics at all in his work. His arguments are very sensible in the actual context, because the accuracy the calculation of scales provides in this project goes far beyond the required level of accuracy in making the cardboard model. The student realises that the suggested tool (calculating scales) is not well suited for the purpose, in line with how Norman (1998) was warned against a too strong focus on mathematical optimisation during the development of ideas in technology and design. This is only significant when most of the design activity is over and the problem has been reduced to one that is well defined. The student's reaction resembles what constitutes the core of technological activity as dynamic and situated, where knowledge, tools and procedures are chosen in pragmatic ways to fit the desired outcome (Ropohl 1997). If the benefit is negligible, there is no reason to spend the cost of enhanced accuracy.

Clearly, student projects could be better designed in order to incorporate science and mathematics in more direct ways. Other studies have pointed to that also pedagogy and teacher competence are important (McCormick and Evans 1998; Norton and Ritchie 2009; Sidawi 2007). These are all crucial elements in developing high-quality technology teaching. However, our analysis indicates that the challenges are not only a matter of good project design, pedagogy or teacher competence; they are deeply situated in the nature of the knowledge involved. All the four issues identified in this study concern fundamental aspects of the nature of technological knowledge and practice in explaining the lack of content knowledge from science and mathematics in technology projects. Our study suggests that the technological problems students typically encounter in technology projects are not best solved by the conceptual knowledge these subjects offer on school level, unless the project is specifically and carefully designed for this particular purpose. In that case, however, projects would be less authentic as technology and design projects.

4.8 Conclusion: How Can Projects in Technology and Design Serve as Learning Contexts for Science and Mathematics?

The results presented in this chapter suggest that problems of incorporating science and mathematics in technology and design projects are strongly related to fundamental characteristics of technology as knowledge and practice. Concepts and principles from science and mathematics may be relevant in a theoretical sense, but often not of any use for students in performing the technological task. Instead, technological tasks require technological knowledge.

Based on these results we suggest that technology and design should be given a clear identity in its own right in the curriculum. However, multidisciplinary approaches should still be encouraged. Technology and design projects may provide contexts and experiences that can be utilised in constructive ways for science and mathematics learning. As examples, the three projects presented in this chapter could provide contexts for students to work conceptually with concepts and principles related to scale, electric current, forces and movement. This subject content could be taught *after* the students have got some experiences with material and technological challenges in the relevant situations without being seen as prerequisites or functional tools for attaining the technological outcome. The practical contexts can this way serve as examples that function as stepping stones to the more general concepts and a more general understanding.

Norton and Richie (2009) have discussed the two approaches *just in case* and *just in time* for how conceptual knowledge can be taught in relation to a practical project. The former implies that the conceptual content is taught before the project, and the latter implies that it is taught when the need occurs. In light of our results and perspectives on technological knowledge, our suggestion would rather be a *just afterwards* approach. This would involve that practical projects in technology and design have their focus on technological knowledge, but that projects students have worked with could thereafter serve as relevant contexts and a source of experiences to explore conceptual knowledge from science and mathematics.

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References

Barlex, D., & Pitt, J. (2000). *Interaction: The relationship between science and design and technology in the secondary school curriculum*. London: Engineering Council.

Bencze, J. (2001). 'Technoscience' education: Empowering citizens against the tyranny of school science. *International Journal of Technology and Design Education, 11*(3), 273–298. doi:10.1023/A:1011247002142.

Boon, M. (2006). How science is applied in technology. *International Studies in the Philosophy of Science, 20*(1), 27–47. doi:10.1080/02698590600640992.

Bungum, B., Esjeholm, B. T., & Lysne, D. A. (2014). Science and mathematics as part of practical projects in technology and design: An analysis of challenges in realising the curriculum in Norwegian schools. *NorDiNa, 10*(1), 3–15.

de Vries, M. (1996). Technology education: Beyond the "technology is applied science" paradigm. *Journal of Technology Education, 8*(1), 7–15.

Dundas, A. A. (2011). *Hva skjedde med teknologi i skolen? En studie av læreres erfaringer med teknologi og design i grunnskolen.* Master thesis, The Norwegian University of Science and Technology.

Gardner, P. (1994). Representations of the relationship between science and technology in the curriculum. *Studies in Science Education, 24*(1), 1–28. doi:10.1080/03057269408560037.

Hansen, R. (1997). The value of a utilitarian curriculum: The case of technological education. *International Journal of Technology and Design Education, 7*(1), 111–119. doi:10.1007/978-94-011-5598-4_10.

Hughes, T. P. (1986). The seamless web: Technology, science, etcetera, etcetera, etcetera. *Social Studies of Science, 16*, 281–292. doi:10.1177/030631278016002004.

Jones, A., Buntting, C., & de Vries, M. (2013). The developing field of technology education: a review to look forward. *International Journal of Technology and Design Education, 23*(2), 191–212. doi:10.1007/s10798-011-9174-4.

Layton, D. (1991). Science education and praxis: The relationship of school science to practical action. *Studies in Science Education, 19*(1), 43–79. doi:10.1080/03057269108559992.

Lewis, T. (2009). Creativity in technology education: Providing children with glimpses of their inventive potential. *International Journal of Technology and Design Education, 19*(3), 255–268. doi:10.1007/s10798-008-9051-y.

McCormick, R. (1997). Conceptual and procedural knowledge. *International Journal of Technology and Design Education, 7*(1–2), 141–159. doi:10.1023/A:1008819912213.

McCormick, R., & Davidson, M. (1996). Problem solving and the tyranny of product outcomes. *Journal of Design and Technology Education, 1*(3), 230–241.

McCormick, R., & Evans, H. (1998, August 27–30). *The use of mathematics in secondary school D&T*. Paper presented at the British Educational Research Association Annual Conference, Belfast. http://www.leeds.ac.uk/educol/documents/000000808.htm. Accessed 19 Nov 2014.

Merriam, S. B. (1998). *Qualitative research and case study applications in education*. San Francisco: Jossey-Bass Publishers.

Norman, E. (1998). The nature of technology for design. *International Journal of Technology and Design Education, 8*(1), 67–87. doi:10.1023/A:1008827820764.

Norton, S., & Ritchie, S. M. (2009). Teaching and learning science and mathematics through technology practice. In A. Jones & M. de Vries (Eds.), *International handbook of research and development in technology education*. Rotterdam/Boston/Taipei: Sense Publishers.

Petrina, S. (1998). Multidisciplinary technology education. *International Journal of Technology and Design Education, 8*(2), 103–138. doi:10.1023/A:1008889513151.

Ropohl, G. (1997). Knowledge types in technology. *International Journal of Technology and Design Education, 7*(1), 65–72. doi:10.1023/A:1008865104461.

Sidawi, M. M. (2007). Teaching science through designing technology. *International Journal of Technology and Design Education, 19*, 269–287. doi:10.1007/s10798-007-9045-1.

Staudenmaier, J. (1985). *Technology's storytellers: Reweaving the human fabric*. Cambridge, MA: Society for the History of Technology and the M.I.T. Press.

The Norwegian Directorate for Education and Training. (2006). *Curricula for subjects in primary and secondary school*. Oslo: The Norwegian Directorate for Education and Training.

Vincenti, W. G. (1990). *What engineers know and how they know it: Analytical studies from aeronautical history*. Baltimore: Johns Hopkins University Press.