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Science and mathematics as part of practical projects in technology and design: An analysis of challenges in realising the curriculum in Norwegian schools

Abstract

Technology and design is seen by many as having a potential for students to work with science and mathematics in practical contexts. The view is particularly evident in the Norwegian curriculum, where technology and design is defined as an interdisciplinary topic involving Science, Mathematics and Art & Crafts. This paper reports from a video study of the use of mathematics and science in student projects in technology and design. It was found that the projects contained very little conceptual knowledge from mathematics and science even when their purpose was to do so. In this paper, we analyse four selected episodes in the material, and discuss the underlying cause for why science and mathematics do not form part of the activity. These underlying causes are conceptualised as: (i) concepts and procedures not being necessary for the purpose, (ii) problem solving better accomplished by other means, (iii) focus on product quality, and (iv) not the right type of knowledge. These reflect fundamental characteristics of the nature of technology rather than to pedagogy, and the results suggest that technology and design as a domain of knowledge should be represented in the curriculum in its own right and not as an arena for learning science and mathematics.

Introduction

The knowledge component of technology in the school curriculum remains a contested terrain (see e.g. Jones, Buntting, & de Vries, 2011). 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 highly use of scientific knowledge in its development. This ambiguity is reflected in the challenges represented in defining technology as a school subject worldwide.

In the Norwegian curriculum, technology and design is placed as a cross-curricular field in the subjects Science, Mathematics and Art & Crafts. This curriculum arrangement is built on the rationale that technology and design provides motivating and relevant contexts for the students to work with conceptual content from science and mathematics. The research presented in this paper is a video study from six Norwegian classrooms where students work with practical projects in technology and design.

In order for students to actively deal with conceptual knowledge, this knowledge needs to be articulated in verbal forms. Accordingly, we chose to do a quantitative content analysis of dialogues between teacher and students. As shown by Esjeholm (2013), and summarized in the result section, this analysis revealed that virtually no conceptual knowledge from science and mathematics was addressed in the dialogues. In the present paper, we investigate this finding further by analysing selected episodes from the material analysed by Esjeholm (2013) in the video material, with the research question

- *How can the absence of science and mathematics content in D&T projects be explained in light of perspectives on technological knowledge?*

The episodes are chosen based on where teachers and the research teams initially believed that science and mathematics would be well represented.

Perspectives on technological knowledge

The positioning of technology and design in the Norwegian curriculum actualizes various perspectives on the nature of 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. Gibson, 2008; 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).

Based on his thorough analysis of what constitutes technological knowledge, Staudenmaier (1985) has stated that no technological praxis is completely reducible to abstract theory. However, he provides four characteristics of technology as a domain of knowledge: Scientific concepts, engineering theory, problematic data and technical skills. Scientific concepts represent tools in technology as far as they are appropriate for the given context. Engineering theory is the knowledge gained by systematic experimentation forming a formal and coherent intellectual system, while problematic data denote approximations made where theory does not offer solutions to specific problems. Finally, technical skills denote practical knowledge that in its form is not reducible to conceptual knowledge.

Staudennmaier's categories of technological knowledge illustrates that even if technology is deeply situated in practical contexts, the knowledge also comprise knowledge that is theoretical and generic in nature. This corresponds to how (McCormick, 1997) has described technological knowledge as either conceptual or procedural. Conceptual knowledge comprises general declarative knowledge that may be scientific or technological in nature, in line with Staudenmaier's categories Scientific concepts and

Engineering theory. Procedural knowledge is related to how to perform processes such as design, modelling, problem solving and quality assurance. This knowledge is practical and based on experience in relevant contexts.

The above illustrates that technology comprises much more than the application of pure scientific knowledge. Nevertheless, science and technology are highly interrelated in their modern form. Not only does modern technology build on advanced scientific knowledge, but the advancement of science is also highly dependent on technology. Science and technology are hence described as a 'seamless web' (Hughes, 1986). In line with this, Ziman (1984, 2000) has pointed to how science has developed into what he denotes 'post-academic science', forming part of technological and economic development and aiming at production rather than knowledge for its own sake. Despite this development science and technology is 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.

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. As the school curriculum is structured around conceptions of disciplines, major efforts have been made to conceptualise the disciplinary content of technology as a school subject. One reason for the challenges in this regard might be that technological knowledge in its nature does not carry the structure of an academic discipline. Rather, it acquires form based on purposes in specific human activities, and is interdisciplinary in its use of formal knowledge (Herschbach, 1995).

Related to these problems of conceptualising technological knowledge, cultural and institutional settings also contribute to challenges in introducing and maintaining technology as a domain in the curriculum. In a major review of recent developments internationally, Jones, Buntting and de Vries (2011) describe the field as fragile in terms of status of the subject, establishment of professional bodies, support for teachers and the socio-political environment of schooling. A main challenge is to conceptualize the identity of the subject, its disciplinary content and relationship to other subjects.

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 straight-forward applications of science and hence don't do justice neither to technology, nor to science (e.g. Boon, 2006; de Vries, 1996; Gardner, 1994; Layton, 1991). In particular, the critique has been directed towards how presentations of technological applications in school science indirectly create an image of technology as inferior to science as a domain of knowledge.

Other traditions of technology education places 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., 2011).

While technology as a subject for all students makes technology more visible in the curriculum, many have pointed to that the close relationship that exist between science and technology should be represented in how students engage with science and technology in their general education (Barlex & Pitt, 2000; Bencze, 2001; Hadjilouca, Constantinou, & Papadouris, 2011; Lewis, Barlex, & Chapman, 2007; Petrina, 1998; Sidawi, 2007). Rather than teaching technology as applied science on one hand, or as separate subjects on the other hand, it has been argued that science and technology should be taught in partnership (Fensham & Gardner, 1994), or as 'technoscience education' (Bencze, 2001; Tala, 2009). On a broader basis, Petrina (1998) advocates a view of technology as multi-disciplinary, and that curriculum development should draw on a range of knowledge domains rather than searching for a mono-disciplinary identity of the subject.

Also for mathematics teaching, several studies points to the potential for integration with technology (Norton & 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 value of the subject.

The above may entail that knowledge in science and mathematics is a resource for technological activity and that technology projects may provide fruitful context for both applying and learning science content knowledge. However, this is not as straight forward as it may seem. Sidawi (2007) has through a review of research literature identified three main challenges in attempting to include science knowledge in teaching technological design: teachers lacking understanding of the complex relationships between science and technology, students are not able to transfer science knowledge to designing technology, and teachers lacking a deep understanding of the design process. She concludes that students need support in order to acquire the necessary science knowledge needed for the design, and to transfer this knowledge into the relevant context. Similar results regarding transfer of knowledge between contexts have been found in mathematics (Norton & Ritchie, 2009). Empirical studies also show that differences in classroom culture between mathematics and technology with regards to the use of language, units, procedures and concepts represent obstacles for students in applying their knowledge of mathematics in technology and design activities (McCormick & Evans, 1998).

The approach to technology and design in the Norwegian curriculum

The current Norwegian curriculum was introduced in 2006 (Utdanningsdirektoratet, 2006). After a long debate on the possibility of establishing technology as a subject in its own right, technology was represented as topic entitled "technology and design" across the subjects Science, Mathematics and Art & Crafts in the curriculum. The idea underpinning this arrangement was that the domain of technology and design constitutes meaningful and motivating contexts for learning and using knowledge from science and mathematics and should hence be taught as part of these subjects (see Bungum, 2004). The Norwegian curriculum model for technology and design hence provides an opportunity to investigate the potential for learning science and mathematics through practical projects in technology and design.

In the specific curricula for subjects in the Norwegian curriculum (see Utdanningsdirektoratet, 2006), we find quite differing approaches to technology and design. The subject Art & Crafts has "Design" as a main subject area, covering mainly techniques for producing material objects in primary school, and broadened to contain aspects of user friendliness, environmental issues and design as part of culture in lower secondary school. In Science, "Technology and design" forms a main subject area, focusing on the planning and making of products, mainly involving mechanics or electricity. The curriculum for Mathematics is more clear on the subject's contribution as applied knowledge in design and technology. The introduction to mathematics in the formal curriculum states that *"Mathematics shows its usefulness in practical applications and as a tool in technology and design"*. The specifications of competence aims state several places that students should use specific skills in mathematics in technology and design contexts.

The subjects involved are to little degree coordinated with regards to technology and design in the curriculum. The ambiguity of what constitutes the core of technology and design as a domain of knowledge opens up for a range of different approaches, within and across the subjects where technology and design is represented. There is little systematic evidence of how the subject area is realised in schools, but a small survey indicates that many schools do not pay particular attention to its cross-curricular nature in the curriculum (Dundas, 2011).

In the study presented in this paper, we attempt to throw more light on the issue of learning and applying conceptual knowledge from science and mathematics in projects in technology and design, as this forms part of the rationale for technology and design in the Norwegian curriculum. The study investigates how conceptual knowledge from science and mathematics come into play when students work with projects in technology and design. Conceptual knowledge is here 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, under guidance of their teacher, deal with and communicate knowledge and activities in three extensive cross-curricular student projects in technology and design developed and implemented in six different Norwegian schools (year 3-10).

Research methods

The research group developed ideas for six student projects and the projects were run in cooperation with local teachers at six different schools that volunteered to participate. The projects are described in Table 1. Each school ran one of the projects. The overall aim for the development of student projects was to contribute to the realisation of technology and design as a constructive cross-curricular field where students work with science and mathematics in practical, motivating contexts in line with the intention of the curriculum.

While the project ideas came from the research group, the projects were adapted and fully taught by the participating teachers. The projects are somewhat more extensive than what is common in schools, but are otherwise not very different from what schools normally undertake with regards to content and working methods. Members of the research group were present during the realisation of the projects, without but influencing teachers' and students' work to any considerable degree.

Classroom sessions related to the project were videotaped. Two cameras recorded two groups of students (2-4 students in each group) and one camera recorded the classroom as a whole. In addition, the main teacher was carrying a wireless microphone throughout the entire project in order to record all teacher-student interactions. The video data constituted ca 150 hours of film displaying student activity.

The groups to videotape were selected by the teachers. They were asked to select groups that would represent the class but where at least one student had shown low school motivation as we were interested in how the project could enhance motivation.

All dialogues between teacher and students in the selected groups have in the first part of the study been analysed quantitatively with regards to the kind of knowledge represented in the conversation. This material amounted to ca 53 hours of video recordings, and the analysis is described in Esjeholm (2013).

In the part of the study reported in the present paper, we have gone deeper into the material and analysed selected episodes with regards to why science and mathematics are *not* represented. The episodes were purposely selected as they provided illustrative examples of situations where the potential for science and mathematics content was not fulfilled. These were situations considered to have a potential for this by the researchers as well as by the teachers. This analysis considers not only dialogues but also students' actions in the project and the objects they produced. The episodes are analysed in light of the aim of the project as a whole, the intentions students appeared to have in their work as well as the perspectives on technological knowledge presented in the foregoing. The result of this part of the study is hence a conceptualization of reasons why the intention of incorporating science and mathematics in the technology and design projects were not fully fulfilled.

Table 1. The six student projects.

Project	Description	Grade	Duration of teaching
A: Model of oil drilling rig	Students use Lego Robotics in combination with other materials to construct a model of an oilrig that simultaneously can lift and move vertically.	8	2 full school days
B: Model of outdoor shelter	Students use Google SketchUp to design a model of an outdoor shelter. The physical model was built in thick cardboard from templates and decorated.	3-7 (combined class)	20 hours during two weeks
C: Model of playground equipment	Students use Google SketchUp to design models of playground equipment, calculate scales and build the model in cardboard and other materials.	8	20 hours during one week
D: Dream house	Students design their individual "dream house" with Google SketchUp and build the model in cardboard using appropriate scales.	9	30 hours during 3 weeks
E: Model of town with lights	The class as a whole construct a model of their hometown from a map. Groups work with different parts of the model, and hence identical scales are necessary in order for parts to fit together. Electric lights are mounted as streetlights on the finished model.	10	8 full school days
F: Scale model of the solar system	The class as a whole construct a model of the solar system with correct scales for size of planets and distance between them. Each student group was assigned one planet and made a model of the planet. To find the position in the terrain, they used GPS navigators. The model of the sun, placed at the school, had a diameter of 1,39 m, and Neptune, the planet furthest away, was positioned 4,5 km away from the school.	5	20 hours during one week.

Results

The quantitative analysis of dialogues in the video material is shown in Table 2. A dialogue is defined as the entire time span from the teacher approach a group until he or she leaves. It is evident from the table that technological knowledge is clearly dominant in the dialogues. Noteworthy, no dialogues at all contain conceptual knowledge from science.

Table 2. Number of dialogues containg conceptual knowledge from technology, mathematics and science (reworked from Esjeholm, 2013). Each dialogue may contain knowledge from more than one category.

Project	Technology	Mathematics	Science	Duration of video analyzed (min)
A. Drilling rig	33	0	0	282
B. Outdoor shelter	29	4	0	492
C. Playground equipment	27	2	0	355
D. Dream house	40	4	0	1197
E. Town model	10	0	0	492
F. Solar system	12	7	0	338
Total	151	17	0	3156

In the following, we present four episodes from the data material that serve to illustrate various reasons for why this is so. It is also briefly described how they represent a larger bulk of data in the material. The subsequent discussion relates the episodes to the perspectives on technology and technological knowledge described in the foregoing, and discusses implications in an educational context.

Episode 1. "I cannot do math! I hate math!"

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 episode is a situation from project C where a student has used the software *Google SketchUp* to construct a model for a playground construction (project 1). This student usually shows low motivation for traditional school subjects, and particularly for mathematics. However, in this project he has worked with strong dedication on designing the playground construction on the computer. The teacher sees this as a good opportunity to get the student involved in calculations of scales for his model. Some of the dialogue runs 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 (angry): 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 does not see it as bringing him any further in the practical task of constructing the model. His rough measure of "30 cm" doesn't need to be further specified by the precise measure resulting from the teacher's calculation. This fits with how Norman (1998) warned against a too strong focus on mathematical optimalization during the development of ideas in technology and design, as this is only significant when most of the design activity is over and the problem has been reduced to one that is well defined.

Episode 2: Town model: how to deal with scales in smart ways

In several of the technology and design 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 selected episode is from project E where students design a model of their hometown and surrounding landscape. In contrast to what was illustrated in Episode 1, correct scales were here essential in order to make different parts of the model fit together. 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 go between three representations when calculating scales: the model, the map and the real landscape.

The following 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 besides 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. With regard to the 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. This has a potential for the other students to learn from. However, the mathematics of the solution didn't get much attention except from the nice and effective way they found to solve the problem. In the end, it didn't give the student group as a whole much experience in dealing with the concept of scales or how they are calculated.

Episode 3. Enlightening the town model

This episode is also from project E, where students are to make lights in their town model. This way they were supposed to cover learning targets about electric circuits 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 and technology-oriented point of view, as the light chains are easily available, relatively cheap and makes 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.

Episode 4. Lifting and drilling: a challenge of mechanisms

In some aspects of the student projects, challenges for students requires understanding of general principles in order to accomplish their tasks. The episode selected represents the model of a drilling rig students are to construct with Lego systems in project A. 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. This was a major challenge for all groups of students.

The Lego set contains a great variety of components that are to be combined 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 was used by students or teacher in any scientific way in the project. This is with good reason, since the mechanisms are better described in terms of operational principles that are technological in nature, and directly related to the components students are working with. The video recordings of the project reveal that students do not possess this kind of knowledge and that this obstructs their progress in the project (see also Esjeholm & Bungum, 2013). Their work to make the desired mechanisms were 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 oilrig. The teacher's guidance of one group of students who were 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 there 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 right track by showing them how mechanisms can be used in order to achieve the desired result. The guidance is highly 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.

Discussion

The four episodes analysed shed some light on why science and mathematics is virtually absent from the technology and design projects, even if conceptual subject matter from these subjects seem relevant for the task.

In Episode 1, the student gets frustrated by the teacher's attempt to bring in mathematics in the activity. This relates to how content from science and mathematics is relevant in the context from the teacher's perspective, but where it does not contribute to the students' activity in the sense of generating a product outcome. The student in the episode 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 context of constructing the model of playground equipment, because the accuracy of the intended calculation of scales goes far beyond the required level of accuracy in making the cardboard model. The student realizes that the suggested tool (calculating scales) is not well suited for the purpose. His 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.

This means that if projects in technology and design are to motivate for and show students the relevance for science and mathematics, knowledge from these subjects needs to be truly needed in order to succeed with the project. In the specific case about playground equipment, this could have been achieved for example by altering the materials in which the models are to be built.

In contrast, the scales are truly needed in Episode 2, where students are to find a common scale for their town model. They do, however, choose to solve the problem by other means, and this 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 (in a broad sense) 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 the way technologists work to a high degree. The student's idea of using the overhead projector in project E seemed to come out of the blue, but was probably influenced by the fact that the map was hanging on the wall and thus providing for the student's association of how an overhead projector can be used for transferring the image of the map to an enlarged template. She has probably 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). This constitutes a way of knowing, as technological knowledge is defined by its use and efficiency, and finds expression through specific applications to particular technological activities (Herschbach, 1995).

This way of dealing with a challenge from a 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 (yet this is not observed in our data material) 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.

In Episode 3 the teacher as well as the students focus is on the quality of the product outcome. 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. Similar results are reported by Mittell and Penny (1997). From our study, we can conclude that this also applies to the potential science learning outcome of the activity. The way the teacher and students approached the task of enlightening their town model makes perfectly sense from a technological point of view. 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 the projects in this study, we found many examples of how desires for product quality diminished the focus on knowledge components from science and mathematics. 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.

In the project about drilling rigs in Episode 4, the knowledge that potentially could be connected to the technological activity is not of an appropriate character for the purpose. Mechanisms for transfer of movement can in principle be described with concepts and principles from physics. However, the associated operational principles (Vincenti, 1990) and engineering theory (Staudenmaier, 1985) are more appropriate for describing principles within 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.

In sum, the reasons for why conceptual knowledge is not represented in the technology and design projects can be summarised as (i) concepts and procedures not being necessary for the purpose, (ii) problem solving better accomplished by other means, (iii) focus on product quality, and (iv) not the right type of knowledge. All these relate to fundamental aspects of the nature of technological knowledge and practice. Many studies of the integration of science and mathematics in technology and design projects have focused on pedagogy or teacher competence (McCormick & Evans, 1998; Norton & Ritchie, 2009; Sidawi, 2007). Our study suggests that the nature of technological knowledge is also an important aspect for why this integration is often not successful.

The outcome of the student projects with regards to science and mathematics content could undoubtedly have been improved by more careful project design in order to create a stronger need for this kind of knowledge. Some examples of potential adjustments in this direction were given in the foregoing. Retaining to these adjustments for the sake of science and mathematics learning could, however, constrict project design along certain lines and hence limit students' experiences of technology as a creative field of work, since creativity involves divergent thinking and ability and opportunities to be open minded about possible solutions (Lewis, 2009). It would also require a more in-depth competence in science and mathematics than the teachers possess, and that they maintained this as a focus rather than the wholeness of the technology & design project.

Conclusion and implications

Our results 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. This should be taken into account in redefining the Norwegian curriculum in direction of giving this area of knowledge a more clear identity in its own right, and not as an arena for working with science and mathematics in practical settings.

The multi-disciplinary approaches should, however, be encouraged. Technology and design projects provide contexts and experiences that can be utilised in constructive ways for science and mathematics learning. However, yet there clearly exist good exceptions, this content knowledge should in general not be mistaken as being prerequisites or functional tools for attaining the technological outcome. As our results indicate, this could diminish student motivation for science and mathematics as well as for the practical project, and in addition create an inaccurate image of the nature of technological knowledge.

Our study has clear limitations in investigating only dialogues between teachers and students and not learning outcomes manifested in other ways. Technology project may benefit students in science and mathematics learning by providing experiences that may contribute to making sense of conceptual knowledge. To activate these experiences, the teacher could address them explicitly in teaching the conceptual knowledge of science and technology. This requires a close link in time between the technology and design projects and the teaching of the relevant subject matter.

Our study has illustrated that, due to the nature of technological knowledge and activity, science and mathematics are neither functional tools in technology, nor will conceptual knowledge in these subjects naturally evolve as a learning outcome from technology projects. Norton and Richie (2009) have described two ways of relating conceptual knowledge to technology projects. A "just in case" approach means teaching the conceptual content before the project and a "just in time" approach means teaching the content when the need occurs. Student projects investigated in this paper are partly "just in case" approaches in the sense that students are supposed to apply knowledge, for example calculations of scales, in their technology and design projects. This task structure is inbuilt in the curriculum for mathematics. Some of the projects also follow a "just in time" approach, except that the need for the conceptual knowledge seldom turn out to appear. The connection could instead, as suggested elsewhere (see Esjeholm, 2013), be made as a "just afterwards" approach, where subject matter from science and technology is taught after the project using the technology project as context and concretisations. The technology and design project could hence serve as a source of experiences to support learning of content knowledge in science and mathematics.

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