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Design knowledge and teacher–student interactions in an inventive construction task

Bjørn-Tore Esjeholm · Berit Bungum

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Abstract The teacher plays an important role in the Technology and Design (T&D) classroom in terms of guiding students in their design process. By using concepts developed within engineering philosophy along with a framework for teacher–student interactions the design process in a T&D classroom is classified. The material shows that four of six predefined categories of design knowledge and three of seven predefined classes of activity are present in the material. Findings suggest that two categories of design knowledge, fundamental design concepts and practical considerations, are particularly significant in the students' work. The teacher's influence with respect to particularly the first of these categories is crucial for the students' design process. Direct trial is found as the students' dominating activity for solving the technological challenges. The results indicate that it is beneficial for students to be introduced to an operational principle before they can be innovative and develop their own design configuration when they establish their fundamental design concept. Curriculum developers, designers of teaching materials as well as teachers should take into account the students' need of sufficient time to explore their design configuration.

Keywords Design knowledge · Teacher–student interaction · Design process · Technological knowledge · Construction task

Introduction

Identifying and conceptualising students' development of knowledge during a design activity remains a challenge in technology education (Jones et al. 2011). Many attempts have been made to relate the analysis of students' development of knowledge in

B.-T. Esjeholm (✉)
Finnmark University College, Finnmark, Norway
e-mail: Bjoern.Esjeholm@hifm.no

B. Bungum
Norwegian University of Science and Technology, Trondheim, Norway
e-mail: Berit.bungum@ntnu.no

technology education to conceptualisations of how professionals work in technology (see e.g. Barlex and Welch 2001; Hill and Anning 2001; Mawson 2007; Roberts and Norman 1999). One recent attempt is made by Rauscher (2011) who investigates the potential of a conceptual framework derived from Vincenti's (1990) categorization of knowledge involved in the historical development of aeronautic engineering. On basis of an empirical, quantitative survey, Rauscher concludes that this framework is constructive in analysing how students report to engage with technological tasks. The survey investigated how students perceived the kind of knowledge they made use of in solving the various tasks. His study also indicated that the categories of knowledge transferred from one context (task) to another.

In the present study we investigate this issue further, by analysing classroom situations where groups of students use Lego Robotics to develop a technological device that is to model a drilling rig to be used in oil industry. We investigate how Vincenti's conception of professional design knowledge can be used to describe students' development of the device. In the educational context, the interaction between students and the teacher is imperative for students' work, since the teacher defines the rules of the classroom and hence often influence the way in which students solve a given task, even if students at the outset are free to develop their own solutions (McCormick 2004). In our study, we analyse how the interaction between students and the teacher influence the design process in terms of choices students make and how they rely on various types of design knowledge.

The research questions for the study are:

1. What kinds of knowledge are represented in students' work with a construction task in terms of Vincenti's categories of design knowledge and classes of design activity?
2. How do teacher–student interactions influence the design process with respect to these categories of knowledge and classes of design activity?

The teacher–student interactions are interpreted in terms of an analytical framework developed by Bräuning and Steinbring (2011) and combined with the categories of design knowledge and classes of activity from Vincenti (1990) in analysing data and discussing the findings.

Perspectives on the design process in technology education

It is widely accepted that technology is a specific form of knowledge and that characterisation of this form of knowledge has relevance for technology education. The nature of technology is described in various ways by philosophers and educators of technology (see e.g. Arthur 2009; McCormick 2004; Mitcham 1994; Ropohl 1997; Staudenmaier 1985). A well-established approach is made by Mitcham (1994) who defines technology as consisting of four distinct and related categories; technology as knowledge, as volition, as activities and as objects. As pointed out by Jones et al. (2011) all of these categories have relevance for technology education. This paper considers in particular the interplay of technology as knowledge and technology as activity.

An important aspect of technology as a form of knowledge is that it is intimately connected to context. Within a situated view of learning (Brown et al. 1989), knowledge is a product of the context where it is developed and used. This perspective on knowledge is highly relevant to technology education, since technical skills and tacit knowledge associated with aspects like material preferences, procedures and design cannot be separated from the purpose and setting of the technological activity. Solving technological problems requires a range of context-based knowledge both procedural and conceptual in nature (McCormick 1997). Tiles and Oberdiek (1995) claim that "Knowledge of the variable conditions of application is as important as knowledge of fundamental theory; practical skills is as important as the theoretical understanding" (p. 104). Hence even if technological knowledge is contextual and relates to practical tasks and situations, theory also forms an important component of technological knowledge. However, as Layton (1991) has pointed out, theoretical knowledge needs to be reconstructed and combined with other forms of knowledge in order to be useful for action in a practical context. This means that technological knowledge is not the sum of distinct categories of knowledge that are either conceptual or procedural, but forms an amalgamation of insights and skills adjusted to the context at hand and immersed in technological activity.

The dilemma remains whether knowledge that is so deeply contextualised is possible to conceptualise in ways that go beyond the particular context and activity. This dilemma has earlier given rise to a focus on process skills, rather than conceptual contents, in technology education. The process approach has been most noticeable in how the curriculum for Design & Technology in England and Wales was built up primarily based on processes as key competencies in the 1990s (see Kimbell 1997; Layton 1994). The idea of structuring the curriculum around process skills has been influential on curriculum development in many countries, but has faded in later years (see Rossouw et al. 2011). In Norway, where the empirical study reported in this paper was conducted, Technology and Design (T&D) in the curriculum was at the outset heavily influenced by the process approach from England and Wales, but transformed into National cultural and educational frames (see Bungum 2006b). The influence can still be seen in how the current formal curriculum makes reference to a "design process". The curriculum document does, however, not conceptualise what the process involves.

Many models for the design process have been proposed in the literature of technology education. In an extensive review of models, Johnsey (1995) found that most of them were linear, typically including subsequent stages that refer to time phases of activity such as Investigation, Invention, Implementation and Evaluation. Some models also form cycles or loops that combine these stages in repetitive ways, emphasizing the iterative nature of design processes.

While the process approach offered a more dynamic view of knowledge in technology than what is captured by approaches merely identifying certain concepts and concrete practical skills to be taught, it has also been subject to major criticism (Hill and Anning 2001; Johnsey 1995; Mawson 2003, 2007; Murphy and McCormick 1997). There are many aspects to this critique. Johnsey (1995) pointed to what seems like a surprising consensus of opinions among authors on the nature of a design process, but suggests that there is a lack of empirical research evidence to support their claims. It has been questioned whether it is feasible to anticipate that design can be described as one generic process that can be transferred across a variety of different problems and contexts (Mawson 2007), due to the highly contextualised nature of technological practice. This critique is supported by empirical evidence suggesting that expert designers as well as novices solve design problems in a variety of different ways (Hill and Anning 2001). The critique suggests that the idea of a generic design process that can be taught, learned and assessed is not only unproductive, but in principle dubious. It is questioned whether a complex process where prior knowledge interacts with creativity and contextual factors whatsoever can be described in linguistic terms or pictured by simple diagrams (Mawson 2003). Hill (1998) has pointed to how the creativity involved in real-life problem solving is diminished in many approaches to design in technology education. Prescribed stages of the process, rather than the problem to be solved and the many opportunities for design solutions, become the prior focus. This may contribute to a rigidity that does not foster students' creativity and real-life problem solving skills. This way the design process may be experienced by learners as a ritual of predefined steps rather than as a creative process that takes a range of knowledge into account (McCormick 2004).

Professional design knowledge: a conceptual framework

As conceptions of the design process as described above consider technology merely as activity, a framework developed by Vincenti (1990) provides for considerations of knowledge as an integral part of the activity in terms of categories of design knowledge. The framework is developed from a detailed analysis of development of engineering design in the case of aeronautics and aeroplane design. Vincenti investigated the problems that arise when technology is invented, developed and refined and the kind of knowledge involved in this process. Though he deals with professional engineering design within aeronautics, his categories of knowledge are of a general kind for all technology design. His focus on the creation and development of technology may hence have relevance for analysing students' work with Technology & Design tasks. In this context, 'invention' is taken to be solutions students develop and that is new to them and their peers, yet it of course might be well-known in the world of engineering.

In his analysis, Vincenti identifies six different nonexclusive and nonexhaustive categories of design knowledge; (1) *Fundamental design concepts*. Within normal design the designer has a fundamental understanding of how the concept is working. Designers have to understand what Polanyi (1967) denotes "The operational principle" of the actual device. The operational principle for an airplane wing is for instance lift caused by air flowing over and under the wing. Operational principles are also found in each component that constitutes a technological artefact. The fundamental design concept defines the device, as in this example an airplane wing, and will in technical sense define the success criterion for the artefact. If the artefact is working according to the operation principle it is a success. The designer will within normal design take "the normal configuration" for granted. Vincenti describes this as how "the general shape and arrangement that are commonly agreed to best embody the operational principle" (p. 209). A common operational principle and normal configuration defines the normal design of a device. If the operational principle is unknown the designer will be in a modus of radical design where there is no outlined process the designer can follow. This may also be the case if a known operational principle is given a new and unknown configuration. (2) *Criteria and specifications.* The general qualitative ends for the artefact have to be translated into specific, quantitative goals expressed in technical terms. This forms a complicated process, but is not always recognised as knowledge. (3) *Theoretical tools* span from intellectual concepts for design to mathematical methods. These cover a spectrum from issues that are normally considered as science to pure engineering tools. (4) *Quantitative data* are usually empiric and may be both descriptive and prescriptive. These data will typically be represented in tables and graphs. (5) *Practical considerations* consist of less precisely defined considerations extracted from practical experience. These considerations are typically unconscious and are often not documented in written form. Feedback from users of the technology will often contribute to the development of experience of this kind. Sometimes practical experience will result in well-defined rules for design and will thereby fall into a different category than this. (6) *Design instrumentalities.* Within normal design a set of well-known more or less structured procedures will be used. One fundamental procedure is to break an overall system down to subsystems. Another is optimisation through iterative procedures. This category also includes judgemental skills that amongst others include visual thinking, intuition and feeling for elegance. These skills are tacit and can be learned only through practical experiences.

Vincenti (1990) shows that knowledge in all of the categories presented above is generated by various kinds of activity. The notion of activity generally covers seven classes including transfer from science, invention, theoretical engineering research, experimental engineering research, design practice, production and finally direct trial. In school projects the classes of theoretical engineering research, experimental engineering research, and production seem generally less relevant and can be omitted. This leaves us with the activities *transfer from science*, *invention*, *design practice* and *direct trial* as classes of student activities that can be expected to foster the categories of design knowledge.

A framework for teacher–student interactions

The teacher's interactions with students are crucial in technology teaching as in all educational matters. As for example McCormick (2004) has shown, the teacher's communication with students during their work process is highly influential on students' progress and decisions, and hence on their learning outcome.

In mathematics education, Bräuning and Steinbring (2011) have developed a framework of four categories of teacher–student interactions. This framework is based on the view of mathematics as a dynamic field of problem solving and an arena for knowledge investigation rather than knowledge transfer. This means that students are encouraged to develop their own ideas rather than reproducing knowledge, and the framework has thus relevance for technology education. Interactions between the teacher and individual students are classified along a dimension from direct transfer of knowledge at one end to knowledge investigation at the other, and the categories are denoted instructive, intervening, explorative or moderating interactions respectively. *Instructive* interactions describe the traditional classroom teaching, where the rationale of the interaction is that students are supposed to follow the teacher's instructions. *Intervening* interactions describe interplay between the student and the teacher, but where the communication is limited to assist or to bring back the student to the teacher's intended solution. In *explorative interactions*, both the teacher and the student use verbal communication as springboard for deeper investigations and explorations. Questions asked by the teacher do not require a fixed answer, but aim at developing a deeper exploration of the subject content. Finally, in *moderating* interactions the teacher accompanies the student's solution process by listening and reflecting on the student's messages and encourages further investigation along the lines defined by the student's ideas.

The research context

The student project presented here was conducted in a Norwegian lower secondary school. In the Norwegian curriculum (Utdanningsdirektoratet 2006) T&D is not present as an independent subject but as a cross-curricular topic that forms part of three different disciplines; Mathematics, Science and Arts & Crafts. The motivation for introducing this cross-curricular topic was partly to create an arena for practical use of science and mathematics, and to foster students' creativity, innovation and development of design (Bungum 2006a). The close relationship between science and technology is emphasized by the fact that T&D is most visible in the science curriculum where it forms one of six major areas. Central in the student project in this study was the particular competence aim from the Science curriculum: "The aims for the education are that the pupil shall be able to develop products based on specifications that use electronics, evaluate the design process and assess product functionality and user friendliness" (Utdanningsdirektoratet 2006).

The student project

The student project was developed by the researcher group in close cooperation with the school. It involved two teachers and 25 students at the age of 13–14 years which corresponds to grade 8 in Norwegian lower secondary school. Oil and gas was the heading of a major cross-curricular topic and included designing and construction of a model of a drilling rig for oil exploitation. The model was partly built by using the Lego NXT Robotics system for operation and control. In addition, other materials were used for the chassis of the rig. Prior to the project the students had been introduced to the overall concept of how the Lego system works but they had limited experience in using it for construction and programming. The two electrical motors of the Lego set was supposed to be used for operation of the drill, and the major technical challenge for the students was to develop a way of combining these for creating an artefact that could descend a rotating drill down to the model seafloor made of clay and to penetrate this to reach for the oil beneath. Students worked with the construction part of the project during 1 day (6 h), in groups consisting of 2–4 students.

Research methods

The methodological approach in the present study has aspects of intervention in the sense that the researcher group contributed to the development of the student project. On the other hand, the approach include elements of realist ethnographic methodology as described by Creswell (2007), where the researcher acts in the background reporting as objective as possible the observed "facts". The interpretations of the observed material are then classified into predefined categories. As far as possible the researchers in the present study avoided influencing the classroom activity. When the students called for assistance only their regular teachers would engage in helping them.

The data for the study were mainly collected by means of videotaping the session in the classroom throughout the project. Three cameras were recording two groups of students and the overall classroom situation respectively. In addition a fourth camera was used for recording interesting situations not covered by the other cameras. The principal teacher and one student from each group were carrying wireless microphones adapted to the respective cameras. Each videotape covers approximately 5 h from the classroom.

An interview with the principal teacher was videotaped directly after the project where both the actual project and technology in general were discussed. Elements of this interview have been used as background information when interpreting the video material. The researchers were present during the recording and monitored the classroom activity in order to grasp the context of the video recordings. Notes based on immediate interpretation of the observed activity were taken successively.

Field notes made by the researchers and crude post-scanning of the video material have been used for reduction of the amounts of data. In particular, we identified teacher–students interactions and other presumptive interesting events with regards to knowledge content in the students' work. These episodes have been further analyzed in detail, aiming at classifying the activity and the categories of knowledge that come to expression. The latter analysis was done by two researchers in order to validate interpretations.

Results

The overall process of the two student groups in the project are described below. In addition, two episodes from each of the groups that are presented and analysed in more detail. These episodes serve as examples of the interaction between the teacher and the students in light of Vincenti's categories of knowledge and activity. The four episodes describe typical situations in the observed material where a teacher approaches students for assisting them in their construction of the artefact. The episodes cover a group of three girls and a group of two boys respectively and are analysed consecutively below.

Group 1 consisting of three girls

The girls start out by analysing the content of the Lego box they have been given. They spend about half an hour discussing and playing with the motors struggling with how the two motors can be put together for solving the task. The problem with rotational motion of the drilling shaft is solved rapidly, but the girls cannot comprehend how they can make use of the other motor. They discuss whether it is allowed to hold the drilling device in their hand and lower it manually. Frequently they switch between concentrating on the computer software and working with the physical device. They finally call upon the teacher who approaches and clarifies that one of the motors should be used for the rotational motion while the other one should bring the device up and down. He also instructs them not to concentrate on the programming at this stage of the project (T = Teacher; G = Girl):

1. G3: Teacher! Is the shaft meant to penetrate the clay?
2. T: Yes.
3. G3: Does it have to be automatic?
4. T: Yes.
5. G1: How is that supposed to be possible?
6. T: You need one motor for rotation of the shaft [talks slowly, gesticulates].
7. G1: Yes, like this [holds up one motor with a shaft connected to it].
8. T: Yes. And then you need another one to descend the shaft and retract it when the drilling is finished.
9. G2: You can do that with a switch like this [holds up a switch].
10. T: Yes, that is correct, you can use a switch like that one.
11. G1: But how is it supposed to look like, the part that is supposed to penetrate the clay?
12. T: Do you mean the platform or the drill?
13. G1: Well…
14. T: The tip of the drill looks like this [shows a small cog and then leaves the group].

In this sequence the students ask for assistance, and the teacher responds by presenting his intended design concept in a way we interpret as intervening in terms of the framework from Bräuning and Steinbring (2011). In this phase the teacher probably sees this as necessary in order for the students to get some progress in their work.

The girls spend the next 30 min by direct trial; they play with the motors and join them by using Lego bricks in various combinations. The evident problem is that both motors produce rotational motion hence they struggle with producing the translatoric movement of the drill. One of the girls suggests that the problem can be solved by connecting a rod to the rim of the rotating cog of one of the motors. By connecting the other motor to the rod in some way she suggests that a linear movement will be produced by allowing the cog to rotate only 45°. She later realises that the angle can be increased to 180°. She gets no response from the other girls and she is not able to transform and develop her idea into a physical construction. Instead they try out a wire connection between the motors without any success. After a while the teacher approaches and shows them how rotational motion can be transferred into linear motion by, in principle, using two particular pieces from the Lego box:

15. T: The point is; how can you make this motor lift this other one? Have you seen this piece? [Showing the girls a particular Lego brick (a rack)]
16. G3: I know it.
17. T: Yes, is it possible to use this? Because…look… I'm just thinking aloud now, so if I make a mess of it you can just yell at me…[the teacher puts a shaft in the centre hole of the motor and mounts a cog to the shaft]…let's say that there is assembled a cog to this shaft, for instance… the cog will rotate… Ok?
18. G2: Yes.
19. T: So, if you then could mount this part [the rack] perhaps like this [joins the rack and the cog]…do you agree that the this [the rack] will move up and down? [demonstrating the linear motion]
20. G1: [gasping] That was smart! [laughing]
21. T: And that means that this [the rack] has to be joined to that [motor] in some way or the other… Do you understand how I am thinking?
22. G2: Yes.
23. T: Try to work further with this idea.

The teacher here takes a seemingly explorative approach in the interaction by asking how the components should be arranged in order to make one motor lift the other one (line 15). However, students are not given time to go into the exploration. Instead, the teacher gets more specific and turns into what Bräuning and Steinbring (2011) call an intervening interaction, trying to bring the students into the track of his own idea of how the problem should be solved, and asks the students to work further on this idea. The students acknowledge the teacher's solution, and then try to find a way of constructing the drilling device using the principles and configuration suggested by the teacher. However, they soon encounter problems with connecting the two motors in a functional way. After a while they give up and return to exploring the software and the content of the Lego box. When the teacher approaches again he helps them with the critical first steps in joining the motors. The girls then spend the last hour adjusting and optimising the construction until they reach a successfully working artefact based on the teacher's guidelines for the design.

Group 2 consisting of two boys

Like Group 1 the boys struggle at the beginning with the fundamental design of their artefact. They have been told that the two motors in the Lego box are supposed to be used for operating the drilling device but they have problems finding out how. They give up several times but are started up again each time by the teacher who as in the case with the girls tries to keep them on track by repeating the specifications where two motors in conjunction is supposed to be a part of the solution. The boys are successively given small hints of how the task may be solved. After 3 h they have developed a solution where one of the motors is moving the other in a curved path towards the sea floor by connecting one of the motors directly to the cog of the other. The teacher has approached and examined the unfinished artefact (T = Teacher; B = Boy):

24. T: But, what might be the problem here? I don't want to make trouble for you, but if this is meant to drill…
25. B1: Yes.
26. T: And it is placed like this [Puts it vertically over the table].
27. B1: Yes.
28. T: And then it will go up like this [Pivots it around the end of the construction so that the tip of the drilling shaft moves it in a curved path].
29. B1: Yes.
30. T: That means that when you have drilled down to the hole then the shaft will be stuck here [pointing at the lower part of the shaft], Ok?
31. B1: No. You just lift it up here [points to the device].
32. T Yes, but then you have to lift it sideways [demonstrates a curved path]. If you have a shaft that is put down in the ground then you can't lift it like that.
33. B1: No.
34. T: I think the smartest way is to make the drill go upwards [demonstrates a linear motion upwards].
35. B1: Make the total construction go upwards.
36. T: I……I think that
37. B1: [interrupting] Then we just add another motor!
38. T: I think that the problem is that it will go like this [in a curved path] and the shaft will break off…in theory…so may be it should go like this [linear].
39. B2: Then we'll need another motor.
40. B1: We'll just take another motor and lift that one.

The teacher's interaction with the students is here intervening in the sense that the teacher reminds them of the fact that only two motors are available hence the solution proposed by the students is not applicable. He demonstrates this problem and points the students to what he sees as "the smartest way" (line 11). This intervention make the students realise they need another motor. After they have been left to themselves again they try to use the ideas introduced by the teacher but face new challenges in joining the two motors in a functional way. Several times they switch back and forth between their initial idea and the teacher's suggestion. They finally end up with accomplishing their own idea where the drill moves in a curved path.

Later in the process the students call upon the teacher again with new problems concerning the configuration:

41. B1: We have a problem connecting the drill to the chassis.
42. T: Ok.
43. B1: It is too heavy.
44. T: [grabs the artefact] You have to make sure that… [tries to connect the drill to the chassis]
45. B1: No, not like that. We are going to use two more rods.
46. T: Two more rods?
47. B1: Yes, and then we…
48. T: [interrupting] But I think you will need another rod here as well. If you use only two rods it will be too unstable. You need more than that to prevent it from turning.
49. B1: Ok.

The students present the problem which invites for an explorative approach. Again the students and the teacher hold conflicting ideas of how it could be solved. The teacher predicts problems in the students' solution and intervenes by suggesting improvements.

In the last stages of the project both of the groups spend most of their effort optimising their construction. In this phase the teacher's interactions tend to be more of the *explorative* kind where the teacher supports the students' solutions.

Discussion

The main challenge for the students in both groups is to establish the *fundamental design concept*; category 1 in Vincenti's framework. Due to lack of experiences with drilling devices their cognition of the fundamental design concept is not very well developed. Through the teacher's introduction they have realised that the construction should include two motors. Still the students can not comprehend an operational principle of the device. They clearly struggle with the fundamental design concept as they switch between working with the software, looking for parts in the boxes and playing with the motors without having noticeable progress in their work. How to produce the translatoric motion seems to be the most challenging. At this stage the students are not clearly separating the task of the physical design of their construction from the challenge of programming the NXT. This can be seen in line 9 where one of the girls is suggesting the use of a switch for controlling the operation of their drilling device. It takes more than half an hour and further instructions from the teacher before it becomes evident that one of the motors should be used for translatoric motion while the other should be used for rotational motion. In this phase of the project the students are working within the domain of radical design as they have not established an operational principle of their drilling device. Through several interventions the teacher establishes first the operational principle and secondly the configuration. When the operational principle is known the students work hard to develop a configuration, which means finding a practical way of connecting the two motors. One of the girls in group 1 launches an idea of configuration that could have been realised if she had been given support by her fellow students. The teacher was not present and could therefore not respond to her idea. The operational principle launched by the teacher was accepted without objections by both groups, while the teacher's configuration led to discussions and considerations by both groups, particularly the boys. The teacher's intervention in establishing the operational principle of the fundamental design concept was in this project of crucial importance for the students' learning. When they were in the modus of radical design at the beginning of the project they were unable to comprehend an overall understanding of how the challenge could be solved and they seemed to lose interest in the project. As soon as the operational principle was established the students managed to produce several configurations that potentially could have been realised into a properly working artefact. It is evident that the teacher had one particular fundamental design concept in mind for the device and tried to persuade the students to adopt this. The result was that only group 1 finally accepted the teacher's configuration while group 2 developed their own configuration despite the advice from the teacher.

Category 2, *Criteria and specifications*, is more or less totally determined by the teacher through the description and design of the project work, availability of materials and time frame. In group 1 the girls suggest a solution where they hold one motor in their hand although they suspect that this design is not in accordance with the rules set up by the teacher. This is confirmed by the teacher in line 4. In group 2 the students have developed a fundamental design concept that apparently works. The teacher is nevertheless introducing a potential failure with their artefact (line 30) prior to the students' experience which thereby rejects their design. The students respond by suggesting ad hoc the addition of an extra motor (line 37) to move the construction translatoric. This is however not in correspondence with the criteria which allows only two motors to be used and the teacher is therefore not consenting on the students' idea of solution. The teacher's intervention leads the students to eventually leave their idea of using three motors but they keep their idea of a nontranslatoric moving device.

Category 3, *theoretical tools*, and category 4, *quantitative data*, are not found in any of the groups work. Both categories are according to Vincenti closely connected but not restricted to science and mathematics. A typical characteristic of technological concepts we find in this project is that they deal with practical context whereas in contrast scientific and mathematical concepts are related to generalities. In the process of manifesting the design concept into the actual artefact the students have to draw upon any prior knowledge that can be connected to the actual context. They seem to gain knowledge by trial and error through the process more than leaning on theoretical considerations that science and mathematics can offer. The lack of knowledge types derived from science and mathematics is interesting in light of the Norwegian curriculum which explicitly stresses the connection between science and technology. Technology used in oil and gas exploitation relies undoubtedly on advanced science but scaled down to a model used in a classroom the science part of it seems to disappear. In this project it is evident that describing the motion of the motors in mathematical and physical terms is not necessary or even preferable as long as the students realise the basic idea of how rotational motion can be transferred into translatoric or slightly curved path motion through the practical experiences. The process of implementing the basic design concept thus involves more of practical considerations and design instrumentalities than theoretical aspects of the problem. This is in accordance with Vèrillon (2009) who claims that the use and production of knowledge in technology is driven by performative action, artefact design and tool use in contrast to science where it is theory-driven. Verillon points out that artefacts constitute a specific form of technological knowledge as they can be seen as materialised solutions to technological problems.

The teacher interventions are not based on knowledge of category 3 (theoretical tools) or category 4 (quantitative data) in any part of the material analysed. As an example, in line 19 of the girls group the teacher explains the relation between rotational and translatoric motion solely by a practical approach. The lack of category 3 and 4 in our results is in contrast to Rauscher (2011) who found that these categories were as frequent as any of the other. This might be caused by differences in the specific project works investigated, but it might also be caused by different approaches made by the teachers involved. Barak and

Zadok (2009) have studied what type of knowledge students address in working on a robotics project. Their project was designed to incorporate what they call scientific-technological knowledge where the teacher in various ways presented learning units containing scientific topics parallel to the project work. They concluded that this use of informal instruction is likely to foster qualitative knowledge on the subject the students are working with. In the project studied here the focus was on the technological challenges of designing and constructing a drilling device. No particular emphasis was put on scientific learning issues apart from what the students might introduce themselves through working with the project.

Throughout the project we find category 5, *practical considerations* both in the students' own work and in the interventions made by the teacher. The teacher's intervention connected to this category can be seen explicitly in line 30 and in line 48 of the two boys' conversation with the teacher. After the groups have decided on their fundamental design they spend much of the time finding practical ways of constructing their device to a properly working artefact. Several times they experience through trial and error that the construction is too fragile and needs to be slightly strengthened and rearranged. Most of the practical considerations made by both the students and the teacher are tacit and unconscious. The teacher's implicit decision of offering other material rather than Lego bricks for the chassis can serve as an example of more subtle representations of this category.

The teacher has a major role in establishing Category 6, *design instrumentalities.* This is found from the start where the students exploring the software are given instructions of leaving the software until the artefact is finished. The teacher is also evaluating the artefacts during the process and encourages the students to optimise their design. As pointed out by Vincenti (1990) when working with technology the term "satisficing" is often more relevant than optimising. A designer, as the students in this case, will tend to improve the design until it works properly. This means that once the artefact works satisfactory the design will be accepted even though it might not be the very best solution. The use of judgemental skills for evaluating the design is therefore of more importance than benchmarks and formal criteria. In this project the design is recognised as successful both by the students and the teacher when the drilling rig is able to carry out the task of descending and retracting the shaft.

According to Vincenti's framework the students' design knowledge discussed above will be fostered through their activity when working with the designing tasks of their project. *Transfer from science* will in general generate knowledge in category 3 (theoretical tools), and in category 4 (quantitative data). In accordance with the discussion above these two categories are missing in the material analysed and there is no activity that can be classified as transfer from science.

Invention is solely connected to category 1, fundamental design concepts, and particularly to the modus of radical design. Somewhat unlike how a typical engineer works, the students spend much of their time in the project inventing an operational principle or a configuration. This activity is extremely demanding and it is evident from the analysis that without the teacher's guidance and input to the students concerning the fundamental design concept the students would have given up on accomplishing the task.

As described by Vincenti (1990) day-to-day *design practice* requires design knowledge and also contributes to such knowledge. This contribution is indirect in the way that the design practice reveals problems with the design that requires other activity in order to gain more knowledge. Design practice generates knowledge in category 2 (criteria and specifications), category 5 (practical considerations) and category 6 (design instrumentalities). Although one can hardly speak of students designing on a day-to-day basis as a professional designer does, this activity is yet relevant in the classroom. An example from this project is how students through their design practice establish design instrumentalities. Both student groups started out with constructing their artefacts in order to analyse whether their approach *in principle* could be realised into a working artefact. Whenever hitting a successful approach the students revealed how the construction had to be strengthened and supported, and they refined their approach using this gained knowledge.

It seems that students to a high degree make use of *direct trial* in their designing of the construction. This activity generates knowledge in all of the categories of design knowledge and particularly into the dominant category 5 (practical considerations). Numerous examples are found in the material. An example of direct trial generating knowledge in this category is when the students rearrange their construction several times to make it sufficiently strong and stable. Another example of direct trial as a source for knowledge in category 1 (fundamental design concepts), is where the students as a part of the invention process try to combine the Lego bricks in various manners for establishing an operational principle.

Using Bräuning and Steinbring's (2011) framework for teacher–student interaction we find the category *intervening* interactions as the most dominant. This is particularly evident in the early stages of the project before the students have found the fundamental design concept as in the conversation with the girls (line 15–23) where the teacher launches his own idea of operational principle and subsequently encourages the students to explore this idea. Also in conversation with the boys the intervening interaction can be seen in both of the episodes presented. The teacher's use of "may be" (line 38) and frequently "I think" (line 34, 36, 38 and 48) makes his statements appear as suggestions more than instructions.

In the later part of the project, when students encounter fewer problems, the teacher–student interaction becomes more explorative. The reason for this shift may be that the teacher is less eager to intervene as long as he observes that the students have progress in their work. The two categories *instructive* interactions and *moderating* interactions are not found in the data analysed.

The teachers intervening interactions are in this project connected to all of Vincenti's knowledge categories found in the data while the exploring interactions are connected to the process of optimising which is mainly a part of category 6 (design instrumentalities). The knowledge required to solve the task has been generated by the teacher prior to the project where he has found a fundamental design concept, developed and tested it into a working artefact. The teacher is concentrating on analysing and evaluating the students' work where he uses his already gained technological knowledge to help the students forward. This is evident in several situations where the teacher a priori advices the students to reconsider their design, for example in line 48 of the teacher's conversation with the boys.

Conclusion

The analysis presented here suggests that Vincenti's categories for design knowledge and classes of activities are feasible also for educational purposes. We identify four of the knowledge categories and three of the activity classes defined for technology in a professional engineering setting. The students' work in this material is mainly based on knowledge category 1 and 5, fundamental design concepts and practical considerations respectively, while direct trial is found as the dominating activity fostering these knowledge categories. The teacher's interactions with the students are found to influence the students' design process with respect to all of the categories of design knowledge found in the material. The dominant interaction consists of intervening the students' design process where the teacher leads the students to adopt the teacher's intended solution. In the project presented in this paper, students face their main challenges in identifying their fundamental design concepts (category 1). Teacher's interactions here seem to be of crucial importance. The interactions are mainly of the intervening kind, where the teacher attempts to make students adopt his intended solution instead of assisting them inventing their own fundamental design. This is reasonable since without any known operational principle the task might be too demanding for the students. Depending on the learning demand, the operational principle may need to be explicitly taught to students, in order for them to be creative in developing a configuration. This needs to be taken into account in curriculum development and design of teaching materials, and teachers should be aware of giving students the possibility and time to develop their own configuration once the operational principle is given. More explicit teaching of the conceptual knowledge early in the project may also allow for students to use and generate knowledge within the other knowledge categories at later stages of the design process.

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