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A framework for analyzing technological knowledge in school design projects including models

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Abstract
This study investigates, and further develops, a framework for analyzing technological knowledge emanating from school design projects; a framework that has the potential to be used as a tool for teachers when choosing and planning design projects. The study also intends to answer the research question: What technological knowledge, associated to physical models, emanates from design projects common in Swedish secondary schools. To answer the research question, the framework is used to analyze three design projects common in Swedish secondary schools. The design projects were video-recorded during actual classroom work by using a self-following robot camera. The projects involved three teachers and 70 students in grades 7, 8 and 9. Deductive content analysis of the video-recordings revealed that technological knowledge from four categories – Technical skills, Technological scientific knowledge, Socio-ethical technical understanding and Engineering capabilities – within the framework emanated from the three projects. A new category of technological knowledge was also found, namely Technological research capabilities. This fifth category is related to the capability to search for, and interpret, information about solutions when doing a design. An implication of the conducted study is that design projects are important to enable development of technological knowledge in the school subject technology. However, considering the amount of time a design project requires, there is only room for a few projects in secondary school. Therefore, technology teachers have to carefully choose and combine projects to educate technological literate citizens as well as prepare students for studies and future careers within engineering and technology.

Keywords
Technological knowledge, Models, Design projects, Technology Education.

Introduction
Technology can be defined as the use or the making of artefacts (Mitcham, 1994). Artefacts are produced as the result of design processes, in which technological knowledge is important (de Vries, 2005). Thus, technological knowledge, with a focus on the ability to design artefacts, is important to the curricula in many countries (Norström, 2015). To cater for these curricula aims it is customary for teachers to carry out design projects in their classes to develop the technological knowledge students use in design. Thus, it could be beneficial for teachers and the development of technology education to investigate common school design projects, and the technological knowledge that emanates from them.

In order to perform a study of design projects, definitions of concepts being used are important since the definitions might be different in a school context than in other contexts. A *design project* is an activity whereby students develop a technological solution to a problem. This problem is often presented by the teacher. The solution is often presented in the form of a physical model, which is supposed to be presented, or tested, at the end of the project. Models can be used to analyze and evaluate solutions with regards to the goals and intended functions stated in the problem (de Vries, 2005). In the context of this study a *model* is a physical model, built using everyday materials that represent the final product, but is simpler and lacks many features compared with the intended final product (Citrohn et al., 2022). Thus, the *final product* is often a thought product that the students are, sometimes, supposed to be able to describe using their physical model, sketches, or drawings. To create the model a design process is used. A *design process* is defined as a process whereby students develop and test ideas for the solution of a technological problem using a model of a final product.

In Sweden, teachers have considerable freedom to design their teaching as long as the learning outcomes specified in the national curricula are met. Thus, teachers of technology are free to choose which design projects they want to use in their classes, giving them great freedom in planning. At the same time, this freedom constitutes a challenge for the teachers in planning and choosing suitable projects that will effectively develop students' knowledge. In Sweden, about 200 hours (from grade 1 to 9) is allotted to the teaching of technology. Thus, there is a limit to the number of projects that can be carried out throughout secondary school years. Hence, teachers must choose design projects carefully and wisely. For this reason, it would be helpful for many teachers to have a tool for evaluating design projects to assess the technological knowledge deriving from a project.

There are very few studies, in particular empirical ones, that address technological knowledge arising from school design projects. Design projects are quite open-ended regarding what technical knowledge actually becomes available for the students. This is another argument for conducting this study. Citrohn et al. (2022), in an empirical study, concluded that the opportunities for technology learning in relation to models very much depend on a project's presumptions and openness. Furthermore, Christiaans and Venselaar (2005) and Esjeholm (2015) concluded that limited technological knowledge constrains students' ability to be creative and to produce genuine solutions. Rauscher (2010), however, found that on one hand knowledge is indeed needed for design activities, but on the other hand the same design activities are also knowledge-generating.

The aim of this study is to evaluate a framework designed for analyzing technological knowledge in education. The framework will be applied to three design projects, representative of Swedish schools. To examine and further develop the framework as a tool for teachers in the choosing and planning of design projects, the following research question is examined:

What technological knowledge, associated to physical models, emanates from design projects common in Swedish secondary schools?

A framework for analyzing knowledge in technological education

Based on knowledge traditions, Nordlöf et al. (2022a) have designed a heuristic framework for analyzing knowledge in technology education. However, according to Norström (2014), Swedish technology teachers' perceptions of what constitutes technological knowledge varies considerably. Taking this as a point of departure, Nordlöf et al. (2022b) used their framework (Nordlöf et al., 2022a) to design an interview-study investigating technology teachers' perceptions of technological knowledge. They found, empirically, two new categories (Nordlöf et al., 2022b) in addition to their original framework (2022a). This new expanded framework is used for analyzing the data in this study and is displayed in Table 1.

Other frameworks for analyzing technological knowledge exist (see DiGironimo, 2011) and Mitcham, 1994). However, they were not designed with technology education in mind. For this reason, the framework developed by Nordlöf et al. (2022a, 2022b) is chosen for this study. It should be noted, indeed, that Nordlöf et al. (2022a) applied the framework, with promising results, to the English syllabus for Design and Technology and Swedish curricula for Technology.

The framework consists of five knowledge categories. The first three: Technical skills, Technological scientific knowledge, and Socio-ethical technical understanding, each represent a section of technology education and knowledge traditions. The other two, Engineering capabilities and Civic capabilities, are based on perceptions of teachers. Table 1 displays the five categories, their knowledge-origin, knowledge-use and knowledge-activities.

Table 1. The framework from Nordlöf et al. (2022a, 2022b)

Knowledge categories	Knowledge-origin	Knowledge-use	Knowledge-activities
Technical Skills - knowledge *within* technology.	Craftsmanship and other experience-based knowledge traditions. Justified by experience and trial and error.	Taught in crafts and technical education. Craftsmen and technicians.	Making Sketching Drawing Measuring
Technological scientific knowledge - knowledge *within* technology.	Engineering and science knowledge traditions. Justified with scientific methods, although standards and practices are foundations.	Taught in engineering education. Engineers.	Analyzing Calculating Describing Documenting Engineering drawing
Socio-ethical technical understanding - knowledge *about* technology	Humanities and social sciences knowledge traditions. Justified by research methods.	Teach students to discuss and relate to different aspects of technology.	Describing Comparing over time Analyzing Evaluating
Engineering capabilities - how knowledge is used and practiced	Teachers' perceptions of knowledge in technology education.	Prepare students for further studies and work within engineering.	Engineering thinking Project running
Civic capabilities - putting knowledge into a context.	Teachers' perceptions of knowledge in technology education.	Prepare students for life in a technical world.	Decision making

Technological knowledge in relation to the framework

To understand the framework of Nordlöf et al., the categories of knowledge are examined in relation to the philosophy of technology. The technology philosophers Mitcham and De Vries are important to technology education in Sweden. For this study, Mitcham's knowledge aspects of technology (1994) and De Vries artefact-related knowledge (2006, 2019) are the most important.

Mitcham (1994) defines four aspects of technology: Artefacts, Knowledge, Activity and Volition. Within the aspect of Knowledge, most relevant for this study, Mitcham describes four types of technological knowledge: *Sensorimotor skills* or *know-how* is about making and using artefacts.

Knowledge is often acquired intuitively and by trial and error, learning or apprenticeship. *Technical maxims* are the articulating of successful making of knowledge, such as rule of thumb and recipes. *Descriptive laws* refer to knowledge based on experience. *Technological theories* describe knowledge within applied science, for example aerodynamics is an application of thermodynamics and fluid mechanics. Mitcham's four types of knowledge correspond with and support the first two categories, Technical skills and Technological scientific knowledge, in the framework of Nordlöf et al. (2022a, 2022b). Two examples from technology education are design processes and programming, such as following recipes; thus knowledge is based on Technical maxims. Another example is students' learning about making constructions strong and stable, which is knowledge based on Descriptive laws as well as Technological theories.

Technological knowledge is also discussed in engineering philosophy, which could be regarded as a sub-disciple of the philosophy of technology (Mitcham, 1994). Engineering philosophy is normative, giving artefacts a functional as well as a physical nature (De Vries, 2019) that is connected to four different types of artefact-related knowledge (De Vries, 2006). *Knowledge of the physical nature* is about the material properties of the model. *Knowledge of the functional nature* is about the models' functions. *Knowledge of the relations between physical and functional nature* is about suitability of materials for certain functions in models or artefacts. *Knowledge of processes* is about working principles that turn structure into function. Thus, knowledge about the properties a structure might have or is desired to have.

The knowledge-types are relevant for the present study, when examining a project's technological knowledge associated to physical models. For example, students are often required to develop and present a physical model at the end of a design project. When constructing models, students often build them using everyday materials, simpler than the final product. Nevertheless, the model is often supposed to display functions and structures of the final product. In several countries' technology curricula, knowledge of both physical and functional natures of models and knowledge of the relations between them are present. Thus, students are to learn about technological solutions as well as adapting them for expediency. The Swedish curriculum for technology expresses this as "knowledge of technical solutions and how constituent parts work together to achieve expediency and function" (Skolverket, 2021, p1).

Method

This study uses a qualitative methodological approach through a deductive content analysis (Mayring, 2004; Elo & Kyngäs, 2008; Hsieh and Shannon, 2005). Video-recordings from technology classrooms in three Swedish secondary schools were used as primary data. All teachers in the studied classrooms were licensed and experienced, each one carrying out a design project with their students. The projects were chosen to get a variety of different types of projects and because they were seen as being representative of Swedish technology education in compulsory school education. The three projects, named as the *Bridge project*, the *Pedometer project* and the *Greenhouse project*, are described in detail below.

To record activities in the classroom, an iPad was used as a video recording device. For recording of sound, microphones worn by teachers were used. At the same time, these microphones worked as detectors that were followed by a robot on which the iPad was mounted. Thus, when teachers moved around the classroom, the robot targeted the iPad in the direction of the teacher and made sure s/he was followed and video-recorded.

Table 2. Overview of the different project recordings

Project	Recorded lessons	Total lessons in the project	Total minutes of recordings used in the analysis	Grade and number of students
Pedometer project	2	8 x 60 min + spare time for students	95	Grade 8 23 students
Greenhouse project	2	10 x 60 min	110	Grade 9 24 students
Bridge project	2	8 x 50 min	35	Grade 7 23 students

The video recordings had excellent audio quality and the visual recordings of the teachers were also good. The quality of the recording of students' activities depended on the microphone the teacher was wearing, and that the camera followed the teacher's movements in the classroom. Thus, when the teacher was in close proximity to the students, the audio and video recordings were good. This means that the microphone and camera picked up some talk and actions from students when they were near the teacher, even if they were not involved in a direct conversation with them. Disadvantages of using a robot are not being able to correct malfunctioning of the camera but also, not being able to care about the integrity of people being recorded. For instance if, people not intended to be recorded, are entering the classroom during recording. Next, the content and aims of the projects are described.

The Bridge project

In the Bridge project, performed in grade 7, groups of four students were involved in designing a suspension bridge. The bridge was supposed to have a span of 24 centimetres, support a weight of 700 grams for 10 seconds and at the same time weigh as little as possible itself. Prior to the project, the students worked with structures and materials, thus developing theoretical knowledge on making constructions strong and stable. The Bridge project covered in total of eight lessons of 50 minutes each, and during the whole project students had access to weighing equipment to test their bridges. Before starting to build and test their bridge, students' ideas for construction were to be demonstrated to the teacher in a drawing. At the end of the project, before the teacher tested their bridges, the students were supposed to explain and justify their choices of materials and structure. Students had access to materials such as ice-cream sticks and lolly-pop sticks. Furthermore, they had access to tools such as glue-guns, knives, pliers, and saws. When all bridges were tested, the students were asked to evaluate the different groups' bridges from a constructional point of view using their theoretical knowledge. In the final lesson, students were asked individually to present an analysis of their groups' bridge in comparison with the winning bridge, to learn from mistakes. During the project, the students were also required to document progress, sketches, and drawings in their logbooks.

The Greenhouse project

In the Greenhouse project, the students, in groups of four, were asked to design a miniature greenhouse where different functionalities were supposed to be controlled by a micro:bit. The micro:bit was supposed to regulate temperature, light, and moisture by using sensors to give signals to control the lightbulbs, windows, and water systems. The groups of grade 9 students had ten 60-minute lessons to finish their greenhouse. The given task from the teacher was that the greenhouse should be able to keep small plants in good conditions. Few of the students had prior knowledge about programming. At the end of the project, the students were supposed to display their greenhouse and explain and demonstrate functions to the class and the teacher. When constructing the greenhouse, they were able to use rolled office-paper as frames and transparent plastic as glass. At the introduction lesson, the teacher showed how to construct the frames and in the second lesson she demonstrated a variety of everyday materials that could be used in the construction. Moreover, the students also had access to small electric engines, servo motors, LEDs, and other electrical components when constructing different functions. The tools available included scissors, glue guns, pliers and knives. All students had logbooks in which they were asked to write down reflections on their own as well as the groups' processes.

The Pedometer project

In the Pedometer project, the students were, individually, asked to construct a pedometer controlled by a micro:bit. The aim was to construct a model of a pedometer, which was to inspire younger students to walk 10,000 steps per day. An important requirement of the project was adapting the product for sustainability and renewability. They were told, in order to give the project more authenticity, that the model would be evaluated by stakeholders from the Swedish National Board of Health and Welfare. At the end of the project, there was supposed to be an exhibition in which all students were to market their intended final product, the pedometer, by using their model to the stakeholders that in fact were teachers. The grade 8 students had 12 60-minutes lessons to construct the model. Some students had experience of programming and all of them had worked with control and regulation in grade 7. Before starting the project, the students had worked with design and product development theory. When constructing, they had access to materials such as cardboard, wooden sticks, glue, textile cord, plastic, and small metal pieces. They also had access to tools such as scissors, glue guns, pliers and knives, and were asked to write notes and draw sketches in logbooks.

Analysis

The analysis used in this study can be described as a deductive content analysis following the process as defined by Elo & Kyngäs (2008). The process can include testing of existing concepts and categories, as well as sub-categories describing the content of the categories (Marshall & Rossman, 1995). Before starting the Elo & Kyngäs (2008) process, video recordings were made as described above. The first step in the analysis process is the preparation phase, where the researcher familiarized himself with the recordings to get an overview of the material. As parts of the video recordings were made without the researcher being present, this was an important step. The next step was to develop a categorization-matrix based on the framework of Nordlöf et al. (2022a, 2022b). A part of the first categorization matrix is displayed in table 3.

Table 3. Parts of the first categorization matrix used to analyze the data

Knowledge categories with description	Bridge project	Greenhouse project	Pedometer project
Technical Skills Craftsmanship or other types of experience-based knowledge traditions. Justified by experience and trial and error. Making, sketching drawing, measuring			
Technological scientific knowledge Knowledge…			
Socio-ethical technical understanding Knowledge…			
Engineering capabilities			
Civic capabilities			

The next steps were revisiting the data, searching for episodes and actions displaying the technological knowledge gained from the projects. In order to explain how the categorization-matrix was used, a part of the matrix and some examples of episodes are displayed and coded in table 4. In this example, the episode, was categorized as *Technical skills* since it involved making, and using trial and error.

Table 4. Excerpt from an episode categorized as displaying technical skills

Framework (Nordlöf et al.)	The Greenhouse project -
Technical Skills	-You are to make a model, in which you can control the temperature. (Teacher) Action: Students are making openable hatches, in the model, using trial and error.

After categorizing all episodes, it was clear that the category *Civic capability* was not present in the analyzed data. The next step, after excluding the category of Civic capability, was to refine the categorization-matrix by creating sub-categories that would provide more fine-grained descriptions of the knowledge derived from the projects. The category of Technical skills was, for example, refined into four sub-categories: Model building, Sketching and drawing, Programming, and Carrying out a design process. Technological scientific knowledge was refined into two sub-categories: Construction techniques and materials and Sensors and controllers. Socio-ethical technical understanding was refined into Effects on human and environment. Engineering capabilities was refined into Running projects from idea to marketing. Finally, knowledge specifically related to the projects was pinpointed, leading to descriptions such as 'testing functions using trial and error'; see table 5.

Table 5. Part of the refined categorization matrix. Black fields represent a knowledge category being present within the recordings

Technical skills	Bridge project	Greenhouse project	Pedometer project
Model building			
- testing functions using trial and error			

Although the framework of Nordlöf et al. (2022a, 2022b) was used as a point of departure in the analysis, an open mind was kept for new categories of knowledge emerging from the data. This resulted in a new category, *Technological research capabilities*, being introduced to the analysis. This category is about developing knowledge by searching and interpreting technological information that is deemed to be of use to achieve a solution to the design task. As there is a vast amount of information on the Internet related to programming and construction, there is a need for knowledge about how to sift through this information to find what can be applied to the task at hand. Moreover, within the projects, students were also able to develop this knowledge, as they could compare their design solution with solutions on similar problems presented on the Internet. Table 6 displays examples of episodes related to this category.

Table 6. Examples of episodes categorized to demonstrate Technological research capabilities

Knowledge	Bridge project	Greenhouse project
Technological research capabilities	*- We are searching the Internet for solutions and comparing them to our model. (Student)* Action: *Students are comparing their model to applicable solutions on the Internet.*	*- I can help you when googling for applicable programs. (Teacher)* Action: *Students are searching the Internet for applicable programs.*

Ethical considerations of the study

This study follows the ethical guidelines of the Swedish Research Council (Vetenskapsrådet, 2017). The teachers and students were given information about the project and written consent was given before the recordings. The teachers and students could at any point withdraw from the study. Students not wanting to participate in the study were placed in the back of the classroom, out of sight of the camera. The study, registered at Linköping University's personal data processing unit, was pseudonymized to ensure anonymity. The pictures in this study are snapshots from the video recordings and are used with permission of the teachers and students.

Results

The analysis resulted in five categories of technological knowledge, each one consisting of sub-categories arising from the projects. An overview of the knowledge is displayed in table 7. Black fields represent a knowledge category being present within the recordings.

In the following section, the different knowledge types are described in more detail and exemplified using pictures from the recordings of actions, as well as excerpts from conversations, in order to support the understanding of the categories used.

Table 7. Knowledge deriving from the projects; black fields represent a knowledge category being present within the recordings

Technological Knowledge	Bridge project	Greenhouse project	Pedometer project
Technical skills			
Model building			
- testing constructions using trial and error	■	■	
- testing functions using trial and error		■	■
- discussing solutions	■	■	
- displaying intentions of a final product			■
Sketching and drawing			
- designing solutions	■	■	■
- discussing solutions	■	■	
- documenting solutions	■	■	■
- displaying intentions of a final product			■
Programming			
- controlling functions in solutions		■	■
Performing a design process			
- finding solutions to technological problems		■	■
Technological scientific knowledge			
Construction techniques and materials			
- choosing material for model		■	■
- choosing material for final product			■
- building strong, stable and lightweight constructions	■	■	
Sensors and controllers			
- demonstrating functions in technological solutions		■	■
- connecting and controlling micro:bits and sensors		■	■
Socio-ethical technical understanding			
Effects on human and environment			
- adapting sustainability and renewability for solutions			■
- adapting solutions for impacts on emotions			■
Technological research capabilities			
Searching for and interpreting technological information			
- finding and comparing constructional solutions	■	■	■
- finding and interpreting programming solutions		■	■
Engineering capabilities			
Running projects from idea to marketing			
- developing from idea to final product			■
- evaluating and discussing constructional solutions	■		
- marketing final product using a model			■

Model building

All projects displayed signs of technical skills in Model building. In the Bridge project, models were mainly used for trial and error when optimizing material use to minimize the weight of the bridge while still being able to support the predetermined load (figure 1). The students observed and discussed weak points and inaccuracies in the model when loading the bridge. If the bridge held, they tried to remove materials in order to minimize its weight (figure 2).

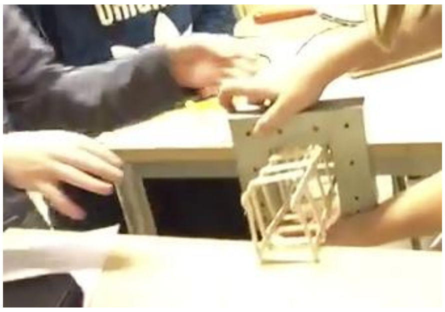

Figure 1. Students loading model in order to test stability.

Figure 2: Student optimizing weight of the model by removing material.

In the Greenhouse project models were used for trial and error when building the framework for the greenhouse. The students tried the stability of different framework constructions. The models also were used when testing functions using trial and error. This could be about testing functions such as opening windows or doors automatically when the temperature got too high.

In the Pedometer project students also used their models when *displaying functions of an intended final product;* for example, displaying an exclusive bracelet, by using everyday materials, supposed to be used in the final product. This demonstrated technical skills in displaying size, functions and materials of the intended final product using models of everyday materials.

Sketching and drawing

All projects let the students practice their skills within sketching and drawing when *designing* and when *documenting solutions*. In the Bridge project, that skill was in discussions both between students (figure 3) and between teacher and students. For example, the discussions could be about the structure of the model, and where support in the form of additional materials was needed.

Figure 3. Students discussing by using sketches

The teacher in the Greenhouse project used the opportunity to emphasize and discuss drawings and sketches when introducing the project:

> *The difference between a drawing and a sketch? The drawing is to be made in scale having measurements, showing what it would look like if it was a full-scale greenhouse. (The teacher in Greenhouse project project)*

In the Pedometer project, students used sketches and drawings when *displaying intentions in the final product.* Thus, the project let students develop skills in using a physical model as well as in making sketches and drawings in order to explain solutions to the final product.

Programming

Both the Greenhouse project and the Pedometer project let the students practice their technical skills in controlling functions in solutions, mostly by using trial and error. Students were programming in a computer and sending the program to the micro:bit for testing different functions within the model. For example, a group of students wanted to control the temperature in their greenhouse by using a programmed micro:bit. When the temperature got too high, the temperature sensor in the micro:bit switched on a fan in the ceiling of the greenhouse. In order to try out the program they had created, the students transmitted their program from their computer into the micro:bit. Then they were able to try out the function by using trial and error. If the program didn´t work, they had to reprogram it on their computer, transmitting it again to the micro:bit for testing in the model. The projects also displayed signs of knowledge about optimizing programs using variables and loops. In the Pedometer project, the teacher urges students to use loops when programming.

> *If we are to program every step from 1 to 10,000 it will be a lot of programming! Instead, we create a variable. Then we have a little box in which we can insert information. When we shake the micro:bit once we want the content of the box to increase by one. Now we have something that counts steps in an easy way. (Teacher in the Pedometer project)*

Performing a design process

A design process was carried out in the Pedometer and Greenhouse projects to find solutions to the projects' design tasks. In the Pedometer project, students applied theoretical knowledge about design processes to a real project, while in the Greenhouse project, knowledge about design processes was quite vague among students, leading to a more intuitive use of a design process. In both projects, but especially in the Pedometer project, the design process was used as a recipe. The students were asked to use a predetermined “design wheel” consisting of five steps, which they were required to follow when designing the Pedometer project.

Construction techniques and materials

The Bridge project let students practice knowledge about *building a strong, stable and lightweight construction* with predetermined materials. The project wasn´t only about building a model but about students using and developing their knowledge about construction techniques. At the end of the project, the students also evaluated and analyzed the construction of the winning bridge by applying their knowledge about construction and materials. This was emphasized by the teacher when introducing the project:

> *Your analysis is important. There you use your skills that you have learned in theory to analyze your own and other people's bridges. What was it about the winning bridge that made it possible to build it both strong and light? (Teacher in the Bridge project)*

The Pedometer and Greenhouse projects let students practice their technological scientific knowledge about construction techniques and materials when *choosing material for the model*. In the Pedometer project, the students also chose materials for the final product, being gaining even more Technological scientific knowledge.

Sensors and controllers

Knowledge about sensors and controllers were, for obvious reasons, displayed in both the Pedometer and Greenhouse projects when *connecting and controlling micro:bits and sensors* and when *demonstrating functions in technological solutions.* An interesting example of this was displayed in the Greenhouse project. The teacher instructed the students to use one function in the micro:bit to display another function. For example, the temperature sensor was supposed to be used to switch on a light or a heater when temperature was too low. However, it turned out to be difficult to test this function since the temperature in the classroom was quite constant. Instead, the teacher suggested students used the light sensor in the micro:bit to test the function of the temperature sensor. The project also let students practice knowledge about micro:bit connectors and sensors, as well as artefacts such as motors, propellers and LEDs that could be controlled by the micro:bit.

Effects on humans and environment

The only project offering knowledge about socio-ethical technical understanding was the Pedometer project. One student was designing a pedometer as a bracelet and *adapting technological solutions to achieve impact on emotions.* Her intention was to have holes for the pin in the strap of the bracelet. She argued that people with wide wrists could be identified, by using that solution. Instead, she chooses to construct a bracelet with Velcro (see figure 4. The Pedometer project also let students practice their knowledge of *adapting for sustainability and renewability in technological solutions*, since this was a requirement of the project.

Figure 4. Student-built Pedometer as a bracelet

Searching for and interpreting technological information

Technological research capabilities were displayed in all projects when *finding and comparing constructional solutions*. In the recordings, it could be seen that students compared their own models of their bridge with real-life bridges found on the Internet. Students actually held their bridge beside the picture of a real-life bridge in order to compare constructions. The Pedometer and Greenhouse projects also let students practice their research capabilities when searching for, and interpreting, information about programming of the micro:bit.

Running projects from idea to marketing

Engineering capabilities were present in the Pedometer project, as the students were to *marketing final product by using a model* to a group of stakeholders during an exhibition. The students were asked to communicate their final product to stakeholders by using a model, practicing their engineering capabilities when ‛translating’ technological solutions to the stakeholders, as well as running a project from idea to product. Thus, students had to use everyday language to describe their technical solutions when marketing. Furthermore, one of the aims of the project was, according to the teacher, to gain insight into the work of an engineer.

Discussion

The aim of this study was to evaluate and develop a new framework for analyzing technological knowledge. The new framework was intended to be used as a tool for teachers when selecting and planning design projects to perform in their classes.

The study fills a knowledge gap about students’ technological knowledge arising from school design projects. Studies from Christiaans and Venselaar (2005) and Esjeholm (2015) examine how students’ technological knowledge affects their ability to create solutions in design projects. The present study examines the technological knowledge emanating from school design projects, thus providing information about how design projects could affect students’ technological knowledge. The present study also supports the results from Citrohn et al. (2022) and Rauscher (2010), which concluded that the opportunities for technology learning very much depend on the project, and that design activities are also knowledge-generating.

The data consists of only three projects in Swedish schools. However, the recordings involve 70 students and three teachers, and consists of about five hours of actual classroom work. Moreover, the projects are representative of Swedish technology education and familiar in secondary schools. The framework used to analyze the projects (Nordlöf et al., 2022) might be considered a general framework for technology education. However, Nordlöf et al. (2022) used the framework for analyzing parts of curriculars containing *Design*, which worked very well. Therefore the framework is relevant and usable for analyzing design projects.

The usability of the examined framework

The framework of Nordlöf et al. (2022a, 2022b) was found to be useful for studying technological knowledge associated to physical models in design projects, and hence was useful for answering the research question. The framework thus proved to be useful for investigating design projects commonly found in compulsory schooling.

The present study argues that Civic capabilities are a knowledge category overarching the others in this study. When Nordlöf interviewed teachers about technological knowledge, they defined *Civic capabilities* as knowledge preparing students for life in a technical world (Nordlöf et al., 2022b). This is consistent to one of the aims of the Swedish curricula for Technology (Skolverket, 2021). Also, Nordlöf et al. argue that Civic capabilities are distinguished by having an holistic approach to putting knowledge into a context, consistent to the overall aims of the subject of technology. Civic capabilities, being an aim for technological education in school, is therefore not used in the framework for knowledge deriving from school design projects, suggested in this study.

Technological knowledge emanating in the projects

Altogether, the three projects impart technological knowledge useful for educating future citizens, as well as preparing students for further studies and working as engineers. However, taken separately, the projects offer different areas of technological knowledge. The Pedometer project covers almost all categories of knowledge within the framework from Nordlöf et al., 2022a, 2022b), while the Bridge project covers Technological skills, parts of Technological scientific knowledge and Engineering capabilities. The Greenhouse project covers almost the same as the Pedometer project, but lacks Socio-ethical technical understanding and Engineering capabilities. Thus, teachers have to be aware that different projects offer quite different opportunities for students to practice their technological knowledge.

The study reveals that the design project is important to technological knowledge in the school subject of technology. Thus the teacher must carefully choose the projects to perform in order to develop a broad technological knowledge. The socio-ethical technical understanding, as well as programming and controlling, are present in the curricula. However, projects involving this content must be carefully planned in order to reach the broad technological knowledge implicated in the curricula. A suggestion for future studies might be to examine more types of common design projects to further develop the framework presented in this study. A special examination of the category Civic capabilities from Nordlöf et al. in relation to other categories is needed.

A new framework for analyzing design projects

In Swedish compulsory school, the number of design projects that can be managed during grades 1- 9 are limited due to the regulated hours of teaching. In order to facilitate teachers' evaluation of design projects, I suggest a further development of the framework from Nordlöf et al. The modified framework is associated to design projects including development of physical models. The framework is based on the findings in this study, and thus the category of Civic capabilities is not included. Instead, the new category of Technological research capabilities is included. Table 8 displays the framework, containing five categories of knowledge, what the knowledge is about, and possible knowledge activities within a design project.

Table 8: A framework for analyzing technological knowledge in school design projects including models

Technological knowledge	Knowledge is about	Activities including models
Technical Skills	- performing a design process – from idea to physical model.	Sketching and drawing Discussing solutions Using trial and error Programming to control functions Building to display solutions Building to display intentions of final product
Technological scientific knowledge	- material properties, different construction techniques and functions of sensors and controllers.	Choosing - material for model - material for final product - constructional technique
Technological research capabilities	- being able to search, interpret and compare information about technical solutions.	Searching the Internet or real life for solutions Interpreting different solutions Comparing own solution to other solutions
Socio-ethical technical understanding	- relating to different aspects of technology.	Adapting to user, society and environment
Engineering capabilities	-preparing for further studies and work within engineering. Using technological scientific knowledge to discuss material and constructional solutions.	Running a design project from idea to final product. Might include marketing product. Discussing different solutions.

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