Affordances of models and modelling: a study of four technology design projects in the Swedish secondary school

Björn Citrohn, Linnaeus University, Sweden
Karin Stolpe, Linköping University, Sweden
Maria Svensson, University of Gothenburg, Sweden
Jonte Bernhard, Linköping University, Sweden

Abstract

This study aims to investigate affordances of models and modelling in design projects in technology education. To learn more about affordances when working with models and modelling, four Swedish technology teachers were interviewed using a narrative approach. Despite a small number of informants data were rich, containing detailed descriptions of sequences where students used models and modelling in ways not planned by the teachers. By using a qualitative, generic inductive approach, the narrative interviews revealed seven different affordances of models and modelling in the projects: *Seeing different solutions; Finding possibilities and limitations in solutions; Representing an idea, structure or function; Communicating solutions with drawings; Making problems and solutions visible; Trial and error and learning from mistakes* and finally *Taking inspirations from each other's solutions.* Some conclusions and implications of the study are that when the students can see and use a wide variety of materials when modelling, they are more creative in finding solutions to design problems. The use of conceptual design in schools, leading to students performing trial and error using models to solve problems, might also be connected to the importance of a variety of materials. In the study, teachers describe how their students used models, trying different solutions, representing ideas, and trying, failing and trying again. All these modelling activities are important parts of a design process and might prove that the doing itself is a process of reflection.

Keywords

Models, Modelling, Design project, Affordances, Technology Education

Introduction

Learning to solve technological problems, as well as learning how to use a design process to solve these problems, are central to many countries' school technology curricula. Models and modelling play an important role in design processes by enabling testing of the qualities and capabilities of a solution and developing it further. However, we need more knowledge about the use of models and modelling in design projects in technology education in compulsory schooling.

In order to learn more about models and modelling, this study examines technology teachers' narratives about successful design projects performed with their students. These narratives could be an important contribution to the knowledge about *affordances* of models and modelling in a design process. Affordances can be described as action possibilities (Norman, 1988). Thus, what possibilities do models and modelling offer to students in the development of technological knowledge in a design process? In a research project of which this study is the third, we aim to deepen and expand knowledge about the use of models and modelling in the school context.

In prior studies, we examined technology teachers' perceptions of model functions in technology education (Citrohn & Svensson 2022) and the use of models and modelling in classroom design projects (Citrohn et al., 2022). While the first study was about *teachers' perceptions*, the second study examined *what actually happened and what was discussed* about models in technology classrooms.

There is also prior research concerning models and modelling in for example, the nature and properties of models were investigated by Nia and de Vries (2017), leading to a framework for analysing models: 'the dual nature of models', consisting of an intrinsic and an intentional nature. An investigation of models and modelling in industrial design led to a classification of physical models like Soft model, Hard model and Presentation model (Isa & Liem, 2014).

A study of models and modelling in STEM (Science, Technology, Engineering, Mathematics) education led to the implication that models and modelling could be used as a bridge between different subjects in STEM (Hallström & Schönborn, 2019). The use of digital models and modelling in technology education (Brink et al., 2021) indicates that technology teachers experience digital models as an amalgam of multiple ideas.

However, none of the above-mentioned studies focus on affordances of models and modelling in school design projects. To our knowledge, a discussion about models and modelling and the affordances of students' use of them in design projects it is still missing in previous research. The present study aims to contribute to the knowledge about affordances that arise when students use models and modelling in unexpected ways that are nonetheless relevant to teachers' plans for the design project. The study uses a qualitative, generic inductive approach, where the data is based on episodic narrative interviews (Mueller, 2019) with Swedish technology teachers in grades 7-9. To meet this aim, the study will answer the following research question:

> Which affordances of models and modelling can students discern, according to teachers' narratives about successful design projects?

Design process, models and modelling

Almost everything surrounding us, except for nature itself, is, in one way or another, designed by humans (Wikberg-Nilsson et al., 2021). The purpose of performing a design process is often to find a solution to a technical problem, perform a development or improvement of an existing product, or to find a completely new product (Wikberg et.al. 2021). Design is described as a purposeful creative act, and it is the basis for creation in a technologically constructed environment (Papanak, 2000). Thus, a design process is not easily defined because of the many uses of the concept in the work of different professional groups. The design processes sometimes differ, but the aim of all process is to produce a design as described by Anthony et al. (2012):

> *Design is a many-splendored activity: architects, engineers, graphic designers, industrial designers, interior designers, landscape designers, fashion designers, computer hardware and software designers (and many others) are all designers, and they all produce a design which is the outcome of a design process (designing). (Anthony et al., 2012, p.93)*

Engineering and technology are professional fields that take design as an important and distinguished activity (Dym, 1994; Li et al., 2019). A design process includes different steps, described in different ways in different contexts, but always starting with a *Problem definition*. This step often includes addressing well-defined to ill-defined questions, with the purpose of getting a view of the problem by identifying the constraints governing it. There are also steps that include *Suggesting solutions* using models, sketches, and drawings to test the qualities and possibilities of a solution and to develop it further. At the end of Dym's design process, there is an *Evaluation and decision-making step* where different solutions are assessed objectively based on their advantages and disadvantages (see e.g., Dym, 1994).

The use of models in a design process in engineering and technology is central to making ideas more accessible to oneself and others, as well as enabling testing and changing solutions before deciding on the final solution (Norström, 2013; de Vries, 2013; Welch, 1998). Physical models are also being used to visualize an idea to a potential customer, or to show a specific function (de Vries, 2018). Furthermore, a conceptual model could be used for planning the whole design process by representing the different phases in the process (de Vries, 2018). In this study, the focus is on the use of models and modelling in a design process, as presented and used in Swedish compulsory technology education.

In general, there are no general differences between modelling in technology and modelling in engineering (Williams, 2011). However, some small but important differences have been shown by research: design in technology is not qualified as science and has no rigorous rules for progression (Lewis, 2005). Furthermore, there is an absence of mathematical analysis in technology (Gettie & Wicklein, 2007). This leads to a division of design into *conceptual design* and *analytical design*, where the former is common in the school context and the latter is more common in the engineering context (Williams, 2011). Conceptual design is less predictive, often leading to a process of finding out what works as a solution to the problem. The solution is evaluated based on its ability to solve the stated problem. In technology education, like in the school context, there are limited possibilities for predicting what works – thus, it is the process of experimenting and modelling that leads to a solution (Williams, 2011). Even expert technologists need to have hands-on experience with their designed products in order to choose the right materials (Potter & France 2018). In analytical design, like in engineering, experimentation and modelling are done to verify a solution before its development (Willams, 2011).

Engineering design is described by the Swedish National Agency for Education (Skolverket, 2021) as consisting of two main parts: *The designing part*, where the idea of the product is launched using sketches, drawings, and a model of the intended product; and *The production part*, where detailed drawings and prototypes, as well as the production of the final product, are carried out (Figure 1). Only the design part, consisting of six steps (*Identification of needs, Investigation, Proposing solutions, Constructing, Testing* and *Documenting solutions*), is performed in Swedish schools (Skolverket, 2021). Regarding the engineering design process (EDP), Dym (1994) proposes five overarching steps, with several small steps within each of them (Figure 1). Important to bear in mind is that there are many ways of describing the EDP, and that the kind of design process being used in school is a subset of the EDP. In the designing part, which is about identifying and researching the problem and developing possible solutions, the materials used might be important. Telier et al. (2011) refer to the term *Materiality* as a technical property of materials from which a designed artefact is made, referring to Mori (2002), who argues that materials are a precondition for promoting ideas and creativity. Telier et al. (2011) argue that in a classroom or a studio for designing buildings, where materials are often random collections of leftovers and samples, finding material for the model may influence the choice of materials for the building. The availability of different materials is necessary for exploring different aspects like the technical, the aesthetical and the conceptual.

The EDP always is connected to a real problem or need; however, the school design process might be connected to an imagined problem or need. When planning a design process in a school context, the teacher might strengthen the connections to the real world, and the complexity, by specifying users and functions (Citrohn et al., 2022) The end of the school design process is of course different from the complete EDP (Figure 1). The engineering design process also includes the optimisation and evaluation of a prototype, as well as communicating the final result in the form of construction drawings and production documents (Dym, 1994). The school design process' possible outcome is often a physical model that might display the student's intentions for the final product (Citrohn et al., 2022).

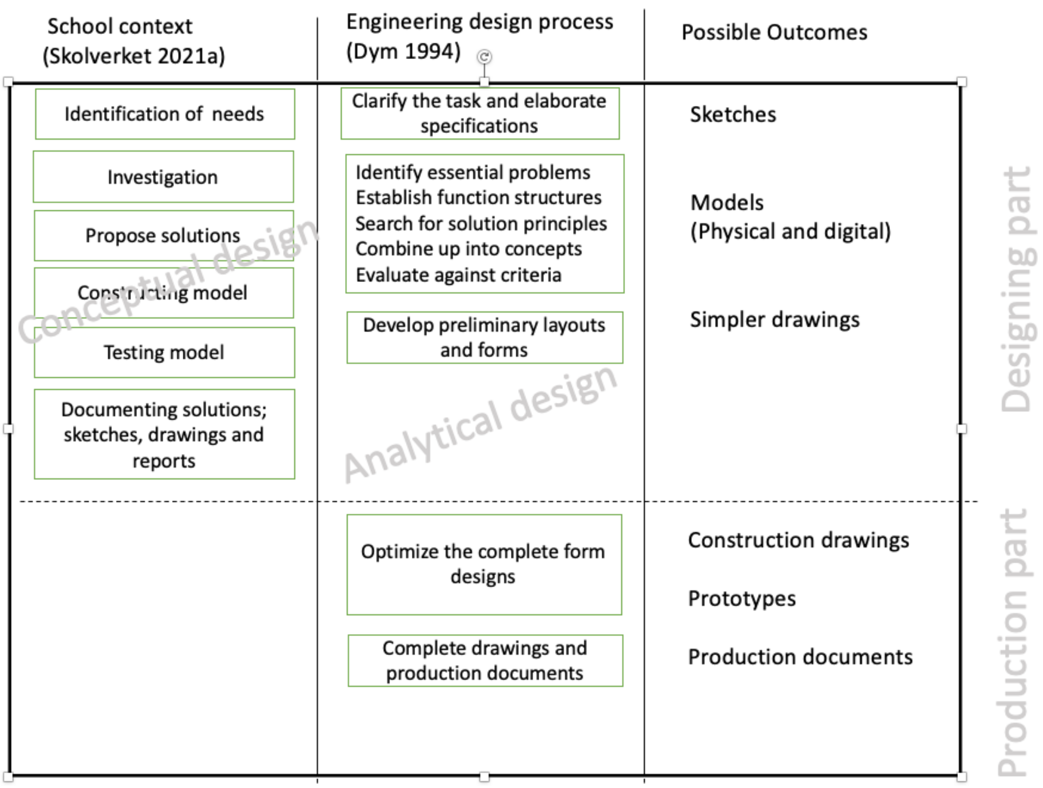

Figure 1: A technology design process and EDP with possible outcomes.

Affordances in a design process

Affordances is about the relation between objects, actors and their connections. James Gibson (1979) defined affordances as offers, or information, that exist in the environment around the actor. The actor has *action possibilities in a certain environment* that are measurable and dependent on the capability of the actor (Teiler, 2011).

In this article we use a definition originating from Norman (1988) who refined Gibson's concept and showed how it could be used in design. He defined affordance as "the perceived and actual properties of the thing, primarily those fundamental properties that determine just how the thing could possibly be used" (Norman, 1988, p. 9). Later, Norman defined action possibilities, affordances, as an *implicit communication* between the designer and the user of a product. He also argues that one important way that people function is the ability to discover and make use of affordances (Norman, 2009).

In this study we use the concept of affordance when examining students' and teachers' use of models and modelling in a design project. Sometimes in design projects, affordances of models and modelling for students and teachers, respectively do not correspond to each other. That is, *students and teachers see different action possibilities in models and modelling*. These instances, in teachers' narratives of a design project, are examined in this study.

Method

To answer the research question, four Swedish, fully licensed, experienced technology teachers have been interviewed. The teachers were selected through a purposive sample (Robson & McCartan, 2016). They were working in different schools, grades 7-9 (students aged 13-15) and were selected for the interviews because they had recently taught design projects involving student modelling. Their projects represent a variety of projects being performed in Swedish schools but also a waste majority of the aims in the knowledge area of *Working methods for the development of technical solutions* the Swedish curricula for technology (Skolverket, 2022). Furthermore, the four teachers performed their projects within five classes, containing in total about 120 students.

Data was collected using Episodic Narrative Interviews (Mueller, 2019). In such interviews, the focus is on a phenomenon, for example an event. In this case a design project is the phenomenon that the teachers were asked to describe in rich detail. They were encouraged to talk about the work with models and modelling in a design project recently performed in their classes. As preparation for the interview, each teacher was asked to answer written questions about a design project that they had performed in their teaching and that they found to be successful. The teacher was invited to describe the aim of the project and to share with the researcher any other information given to the students. The aim of asking the teachers to write about the project was to prepare them for the interviews through reflecting on their projects. The written answers also helped the researcher to prepare for the interview. Moreover, to give the teacher time to reflect during the interview, and thus as an interviewer leave some paus for thinking is important to ensure high quality data (Mueller, 2019).

The interviews were performed and recorded at the end of 2021 via Zoom, an internet-based video conference system.

Ethical considerations of the study

This study follows the ethical guidelines of the Swedish Research Council (Vetenskapsrådet, 2017). The teachers were given information about the project and written consent was given before the interviews. The teachers could at any point withdraw from the study. Since the data consist of interviews with the teachers, consent from the students or their guardians was considered unnecessary. The study was registered at Linköping University's personal data processing unit. The teachers have been pseudonymized to ensure their and their students' anonymity.

In the following section, a summary of each of the four projects is presented. In Sweden, the teacher is free to choose the specific content of projects, as long as the core content and knowledge requirements in the curricula are fulfilled. The four different teachers all work with design projects in technology education, but the content, aims and presumptions differ – hence the four projects represent a variation of design projects in Swedish technology education. All of them are related to the knowledge area of *Working methods for the development of technical solutions* the Swedish curricula for technology (Skolverket 2022). They should be interpreted as four different examples that represent a variation in Swedish technology classrooms.

The bridge project

In the bridge project, the students use their theoretical knowledge when designing strong and stable bridges. The students had theoretical lessons about different materials and how to influence the tensile and compressive strengths but had no prior experience of working with the school design process. The students were to construct a miniature bridge (Figure 2) in the form of a suspension bridge between two desks, in which the lightest bridge which could support a specified weight would be the winner of the project. The students were in grade 7 and worked in teams of 2-3. First, they made a sketch of their intended bridge. Second, after approval from the teacher, they were to build a 3D-model of the bridge. They had access to the internet to search for real bridge constructions (Figure 3). The building material was specified by the teacher and consisted of glue, a glue gun, lolly sticks and matchsticks (Figure 2). The students were able to test their bridges during the modelling process. Finally, all bridges were tested with a specified weight, and the teacher led an evaluation of the construction of the bridges. Pros and cons of the different bridges were discussed, and the students evaluated their bridges individually, in comparison to other students' bridges. The evaluations were noted in logbooks, which had also been used during the construction process to document the design process.

Figure 2: Students building a bridge (Photo from the teacher of the project)

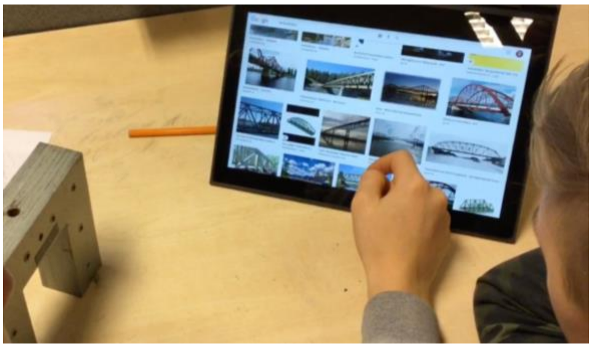

Figure 3: Students examining real bridges (Photo from the teacher of the project)

The optical telegraph project

As a part of a larger project about the history and future of communication, grade 8 students constructed a full-scale optical telegraph from which they could send messages to other students far away. The students had no experience of working with the school design process before, and the only specification given by the teacher was that the optical telegraph was to be built on a large piece of cardboard and that it was to contain nine hatches (Figure 5) that should be operated by the students in order to send messages. The students had free access to materials found in the technology classroom like cardboards, lolly sticks, matchsticks, dowels, rubber bands, cotton string, small wooden boards, tape, glue, and glue guns. Moreover, the students had access to materials from the craft shop. The students worked in teams of 2-3 and were supposed to document their process in logbooks. During the project, the students themselves, without any influence from the teacher or knowledge of the design process, decided to build small-scale models of their telegraphs to try out functions (Figure 4). They had access to different materials and the project ended in testing of the full-scale telegraphs with groups of students standing far away from each other sending messages between them with their telegraphs.

Figure 4. A scale model of a telegraph. (Photo from the teacher of the project)

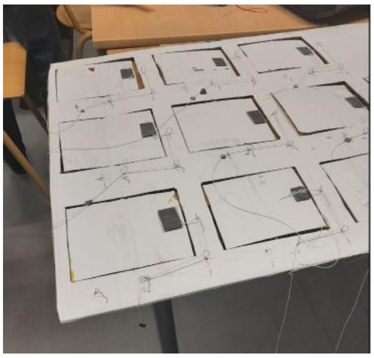

Figure 5: A full-scale optical telegraph (Photo from the teacher of the project)

The design a chair project

In the Chair project, grade 7 students (13 years old) designed a scale model of a chair that was to be used in a school-environment. In reality, the school was about to change classroom furniture, so the project was somewhat authentic. The students, which had no prior experience of design processes, designed the chair from a list of specified criteria such as sustainability, environmental friendliness, ergonomics, and economy. After being presented to the project they started drawing a sketch of the chair mowing on to designing a 3D drawing in Thinkercad. Finally, the students constructed a 3D scale model of the chair (Figure 6). During the constructing phase they had free access to materials in the technology classroom, for example, cardboard, lolly sticks, matchsticks, wood dowels, paper dowels, rubber bands, pulp balls, cotton string, small wooden boards, tape, fabric, glue, and glue guns. Parallel to designing the students were to describe the progress of their design process using text and figures in a logbook. They were instructed to describe their choice of materials and design of their intended final product and the consequences for humans and the environment. The project resulted in many scale models and one goal was to create a catalogue of all the models, with the intention of making it even more authentic for the students.

Figure 6: Scale models of chairs (Photo from the teacher of the project)

The greenhouse project

In the greenhouse project, grade 7 students constructed a scale model of a greenhouse (Figure 7), temperature regulated by a micro:bit controlling a servo opening a window on the roof or the door. The students had not worked with the school design process before, but they had some experience from programming micro:bits. The greenhouses were made using wooden sticks and rolled paper, and the windows were made from plastic film. Materials used in the project included cardboard, lolly sticks, matchsticks, wood dowels, paper dowels, rubber bands, cotton string, straws, and pulleys. The micro:bit was programmed by the students to start the servo to open a window at a specific temperature. Before the students started to build, they made a sketch of their intentions. Then, they constructed their greenhouse and, after finalising them, they made an exact drawing with the measurements. The students also used a logbook to document their design process.

Figure 7: A scale model of a Greenhouse (Perez & Nord, 2021) used with permission from Teknikundervisning i skolan

Analysis

The teachers' written descriptions of their design projects were used to get the broader context of the projects, preparing both the researchers and the teachers for the interview. The descriptions were also used, together with pictures from the teachers, to summarize the projects in the section above. However, the data material used for the analysis in this study consists of the transcriptions of the interviews with the four teachers.

The analysis could be described as an inductive qualitative content analysis (Graneheim & Lundman, 2004). To become familiar with the data, the transcribed interviews were read through several times. The episodic narrative interviews contained rich descriptions of the teachers' intentions and how they were carried out in teaching. One of the strengths of this method is that the interviewees are able to elaborate on the phenomenon. Moreover, the request for details tend to yield rich narratives (Mueller, 2019). The teachers also described the students' activities and how they responded during the project.

In the first stage of the analysis, the first and second author searched the data for sequences where the teacher had an intention with the teaching design, while the students saw other possibilities. This could be episodes where the students came up with new ideas that the teacher had not thought of, or when the students tried too complicated solutions. Hence, these instances are examples of where the teachers and students saw different affordances of models and modelling. After the initial selection, the other two authors were consulted, which resulted in a few changes. In total, 20 excerpts were selected for coding. The coding was performed in two stages – an initial stage with the two first authors, and then a second stage where the codes were confirmed by the other two authors.

The codes were clustered in three different themes, three different contexts, in which different affordances of models and modelling were detected. The themes were; *1. Materials being used in project, 2. Drawings as models*, and finally *3. Process of conceptual design.* These three themes constitute the sections in the results. Of the initial 20 excerpts, the 11 most representative were selected for illustrating the different affordances in the results.

Results

The affordances from the different projects were compiled into the results of the study. When examining the excerpts from the interviews, we were able to identify model and modelling affordances in all four design projects. The excerpts could be connected to three different themes: *1. Materials being used in project, 2. Drawings as models and 3. Processes of conceptual design*. In the three themes seven different affordances of models and modelling were found; *Seeing different solutions, Finding possibilities and limitations in solutions, Representing an idea, structure or a function, Communicating solutions with drawings, Making problems and solutions visible, Trial and error and learning from mistakes and finally Taking inspirations from each other's solutions.* An overview of themes and affordances is displayed in figure 8.

It is important to be aware that the data is based on the teachers' narratives of events in the classrooms.

Theme 1. Materials being used in project

The first theme is related to materials being used in the projects. By using a greater variety of materials when modelling, the students were able to see different solutions when constructing the model. Hence, models and modelling afford *seeing different solutions* by enhancing the cognitive process of designing solutions, when seeing and using a variety of materials. In the optical telegraph project, the students came up with different solutions when working in the technology classroom. However, when they were allowed to visit the craft shop and meet a greater variety of materials which influenced their cognitive models. A cognitive model is an internal representation used to generate external representations, for example a physical model (Buckley 2000). A person's cognitive models can be influenced by models, phenomena and information. When the students were influenced by the materials in the craft shop, they were able to come up with even more solutions and ideas;

> *We have this in the craft shop, we can get it there (students). Students see other solutions than I do, because I only think about the material, I have in front of me. (Excerpt #1, Optical telegraph).*

Thus, the materials offer more possible solutions for the students' modelling. Models and modelling with a variety of materials afford students creativity when finding different solutions. Models and modelling with materials also afford students *finding possibilities and limitations in* *solutions.* For example, optimising the use of materials when constructing. In the bridge project, the students discovered that the actual amount of material could be reduced compared to their original hypothesis. When constructing their cognitive model and their sketches, they believed that they needed more material to make a strong and stable construction. However, when they started building the model, they noticed that material use could be minimised;

> *When they saw that it seemed to be very stable, they realised that they could actually remove some material and didn't have to use it. (Excerpt #2, Bridge)*

The modelling activity affords finding possibilities in the solution. On the other hand, in the greenhouse project, a student had the idea of constructing a sliding hatch, but in this project the materials limited what was possible.

> *There were students who aimed for quite complex solutions and maybe had to back it up later. One student made a sliding hatch, he had some kind of rails, he needed better ropes… A cool technical solution, but it was never finished. (Excerpt #3, Greenhouse)*

The materials afford both what is possible and not possible in construction. The models with the material being used serve as an indicator of possible or impossible solutions. Furthermore, when *representing an idea, structure or a function,* models offer affordances in relation to materials being used. Since everyday materials often are used in schools when representing quite advanced cognitive models, the affordances of models and modelling are helping students represent advanced models with everyday materials. In the chair project, a student wanted to build a chair with wheels. The teacher suggested that he use pulp balls to represent the wheels.

> *We do not have a great variety of materials. A student planned to have wheels on a chair. So, what could we use as wheels? Yes, pulp balls! This looks a bit like wheels, so we used them. You have to invent a lot during the process, I said to the student. (Excerpt #4, Chair).*

In a desk chair with wheels, the wheels are constructed as mechanical moving cylinders with function and structure considerably unlike a pulp ball. However, the teacher suggests the student uses the ball, hence in this model the ball represents an *idea* rather than a function or a structure. The material affords *representing an idea* in the model. In the greenhouse project, the students started to cover the frame of the greenhouse model in plastic film, to represent the structure of a greenhouse. However, the teacher wanted them to focus on representing the function of opening and closing the windows or doors.

> *There were many students who started out with the plastic film, but it is difficult to work with mechanisms if you have covered them in plastic. So, I had to tell them to wait with the plastic film until the end. (Excerpt #5, Greenhouse)*

The students wanted to *represent a structure*, while the teacher wanted to *represent a function*. In this kind of tension, it becomes obvious that the teacher and students see different affordances in the modelling process. Hence, *representing an idea or a function* is an affordance of models and modelling.

Theme 2. Drawings as models

Another cluster of models and modelling affordances is related to drawings being used in the projects. A drawing can be considered a model (Gilbert, 2004) and one example of an affordance is *communicating solutions with drawings.* In the greenhouse project, the students worked in a different sequence compared to the other projects. The students started by sketching the greenhouse quickly – then they constructed the model and tried different solutions. When they were satisfied with their model, they made a drawing of it.

> *They make the drawing based on their model. It is not a drawing of a real greenhouse, but rather a drawing of their model. They do not change in the sketch when they change the model, I think that kills their creativity. They finish the model, and then they make a drawing of the model. (Excerpt #6, Greenhouse).*

This is interesting because a common way to perform modelling in Swedish schools is to evolve the model and the sketch at the same time or make a drawing of the intended product before building the physical model. However, in the greenhouse project, the drawing is a representation of the physical model, not the intended product. Models in forms of drawings have the affordance of *communicating solutions*.

Another affordance of models in the form of drawings is *making problems in solutions visible.* In the chair project, a student made a mistake when constructing the physical model seat. The seat was highly disproportionate in relation to the legs of the chair. The teacher made a drawing in which the mismatch in proportions was displayed in an obvious way.

> *It should look like you can enlarge, everything should be proportional in the model. Someone made a little mistake, and then I drew the model so that the mistake became clear. (Excerpt #7, Chair)*

Models in the form of drawings have the affordance of making a problem, for example the proportions, visible.

Theme 3. Processes of conceptual design

The third theme is connected to *Processes of design.* In our study the process involves the students work from a cognitive model to a solution of the problem in form of a physical model, thus a conceptual design (Williams, 2011). In the bridge project, the students had initial ideas, cognitive models and sketches of how to construct the bridge, but when testing their ideas in a physical bridge and failing, they realised that they had to solve the problem in another way. They did *trial and error and learned from mistakes* when solving the problem.

> *Some students had an idea in the beginning, but in practice some of them reformulated it quite a lot when they realised that the bridge didn't hold anything. They make a bigger journey and actually learned the most. Those who have done the most wrong are the ones who have learned the most. (Excerpt #8, Bridge)*

The teacher in the bridge project emphasised that the students who most used trial and error were those that learned most during the project. When students tried, evaluated and reconstructed their conceptual models, they developed their perceptions of different solutions and of which solution best fits the purpose in different situations. Thus, the affordance of using models is *trying, failing and retrying in order to learn* and to construct and evolve the cognitive models during the process. On the other hand, some students learned at the end of the process. Some students in the bridge project did not listen at all to the teacher's advice on construction – they constructed the bridge following their own cognitive models. However, in the end, when evaluating the bridge, reality caught up, and their cognitive models proved wrong.

> *What's interesting is that some students really think completely freely. They have not listened at all or think that they can do it in a cleverer way. They find another way, but still the analysis phase catches up with them in the end. I really like students who think outside the box in their own way. I think it is important that we affirm this in school and that it is also perfectly okay that it will be wrong. Why was it wrong? The analysis is important. (Excerpt #9, Bridge)*

Thus, one affordance in processes of modelling is learning from mistakes when analysing the result of the process. Another affordance in the process of modelling is *taking inspiration from each other's solutions.* In both the greenhouse project and the bridge project, the students imitated each other's solutions. If a student or a group of students came up with a clever solution, the solution spread through the class and several students started using it. Sometimes, even the teachers spread student solutions between classes.

> *If a student comes up with a smart solution, then other students see it and they start imitating each other. Maybe I show that solution to the next group and then there are many who pick it up. Yes, and I'm trying to urge you to do that. I call it industrial espionage. (Excerpt #10, Greenhouse)*

The affordances of models and modelling in processes is spreading clever solutions. The spreading of ideas might also involve the process itself. In the optical telegraph project, student groups started to build small-scale models in order to solve one function at a time on a small scale (figure 4) before constructing the full-scale telegraph, which contained a lot of functions.

> *Someone came up with an idea of building a small scale-model before building the actual telegraph, which spread through the class. Some students worked with just one box in the small-scale model, and tried to make it work, and then apply it into the large model later. (Excerpt #11, Optical telegraph)*

For the students, taking inspiration from other´s solutions is important for the problem-solving process. The seven different affordances of models and modelling divided into three different themes is displayed in figure 8. Next, we are going to discuss our results and draw some conclusions from them

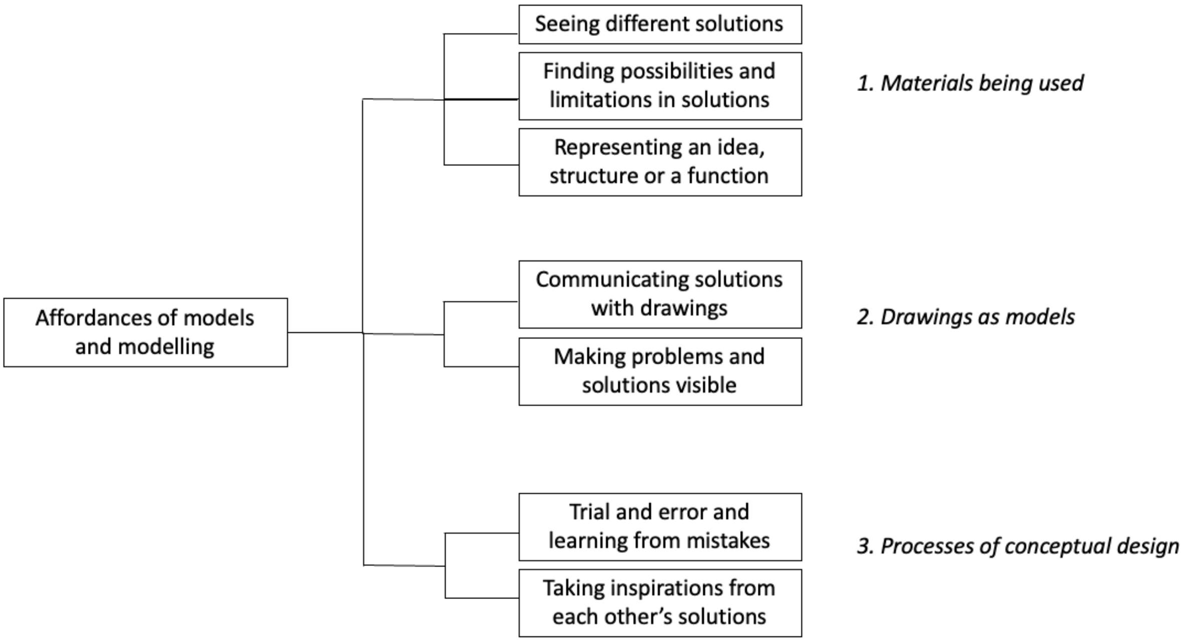

Figure 8: An overview of affordances and themes in this study.

Discussion

The present study answers the research question: Which affordances of models and modelling can students discern, according to teachers' narratives about successful design projects? In this section we discuss and conclude our results.

When using physical models, students in our study were able to *see different solutions* but also *find possibilities and limitations in solutions.* When the students were able to see and use a wide variety of materials, they were more creative when finding a solution. This connects to Telier et al., (2011) and the term of *materiality*, a sort of precondition for promoting ideas and creativity. Moreover, Schön (1983) states that designing could be defined as "a reflective conversation with the materials" (p. 172). Our study indicates that students were able to see different solutions to their problems when they were handling different types of materials. For example, in the Bridge project, when the students only had access to their pre-knowledge, they were restricted to a few possible solutions. However, students that were exposed to a variety of materials, like in the optical telegraph project, found new solutions that they had not come up with on their own. This means that a greater repertoire of materials could give the students new ideas that are not limited to their own pre-knowledge. This implicates that depending on what the teacher wants the students to learn, they could offer different varieties of materials.

Another affordance of the materials is to represent an idea, a structure, or a function. Materials used in technology classrooms are often everyday materials, and the students must display their intentions of the final product with simple materials. For example, the students in the chair project used pulp balls to represent the wheels of a chair (Excerpt #4). The pulp ball represents the idea of a wheel. This might be connected to the complexity of the project, thus if the student is supposed to show their intentions of the final product in their model (Citrohn et al., 2022).

An implication for technology education and technology teachers is the significance of providing students with a rich variety of materials, as this seems to be beneficial for students' creativity (Excerpt #1). Furthermore, earlier research suggests that another important factor for students' creativity is their prior experiences and knowledge (e.g. Esjeholm & Bungum, 2018). Overall, the materials being displayed are important, and we suggest that this relationship between students encountering a rich display of materials and their creativity should be further investigated in more depth and detail.

When examining Figure 1, which includes two interpretations of the design process, the second step of the EDP corresponds to three steps in the school design process: purpose solutions, constructing model and testing model. These 3 steps correspond to the process of modelling and all seven affordances identified in this study. Thus, the usage of models and modelling affords the modelling steps in the design process.

Since our study is connected to the school design process, the process used in our study is about conceptual design (Williams, 2011). Evidence for this is the affordance of *trial and error and learning from mistakes.* The students have to use trial and error to find the right solution, since they are not able to use the analytical design used in the EDP. The school use of conceptual design might also be connected to the importance of a variety of materials in performing trial and error. We suggest further investigations in order to widen knowledge about the variety of materials and conceptual design used in schools.

In summary, this study shows that models and modelling afford more than just unreflective doing. Swedish technology education has been criticised for putting too much emphasis on building and less on reflection (Skolinspektionen, 2014). However, our study indicates that the doing is itself a reflection process. This could be compared with Schön's concept of reflection-in-action (Schön, 1983). Haupt (2018) argues that the systematic approach of a design process requires the students to fill in the gaps and solve the upcoming problems. Our results show that the teachers talk about students trying different solutions, representing ideas, trying, failing, and trying again. All these activities are important parts of the design process that also entails the students to engage in a reflective process (see Schön, 1983). The design process and creative thinking are, and ought to be, chaotic processes. From an outsider's perspective, this might look unreflective and unsystematic. However, the teachers that participated in this study talk about their design projects as successful, and the students explore the materials, the possible solutions and thereby also learn about the design process in an authentic way. Since all four teachers in this study are trained, licensed, and experienced technology teachers, their professional view of what the students do in the classroom have implications for our interpretation of what the students are "doing" when designing.

Furthermore, the affordance *of taking inspiration from others* is an important part of the design process, both in school and real-life contexts. The results indicate that the teachers observe that the students take inspiration from the students that is viewed as being the "clever ones" or the "best ones" on a specific topic. But whether this behaviour really is wise could be questioned. In a similar vein, it is common that students take inspiration from pictures and drawings found on the internet. We suggest that it would be important in future studies to study the relation between these observed, common behaviours and students' creativity when working with a design. Does seeing how others have solved similar design problems open for students to see new, creative, solutions – or do these constrain and limit their vision?

Limitations of the study

This study is based on a small number of interviews that should be seen as four projects representatives of design projects in technology classrooms in Sweden. With this episodic narrative interview technique, the teachers can provide their view on what happened in the classroom. However, we should be aware that the data mirror the teachers' subjective descriptions of the teaching, and that should not be equated with what actually happened in the classroom. As Mueller (2019) states: "a narrative is an internal, subjective account of a socially constructed experience" (p. 8). Even so, we would argue that the professional lens of teachers should be legitimised as accurate for classroom observation and interpretation.

Implications of the study

This study implicates that the materials that students are allowed to use in a design process, potentially will affect their creativity and thereby what solutions they are able to come up with. If teachers want their students to come up with many different solutions, they should offer a great variety of materials. Moreover, our results indicate that the trial-and-error process that the students engage in during design projects, could be interpreted as reflection-in-action, and not just an unreflective act of doing. However, we suggest that the students' more systematic trying could be a sign of more reflected action. This need to be further investigated in forthcoming research.

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