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Teach *to use* CAD or *through using* CAD: An interview study with technology teachers

Helen Brink[1] · **Nina Kilbrink**[1] · **Niklas Gericke**[2]

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Abstract
Today, many technology teachers in compulsory technology education teach design and design processes using a digital design tool, such as computer aided design (CAD). Teaching involving CAD is a relatively new element and not very much is known about what teachers intend pupils to learn in compulsory education. Thus, the aim of this study is to investigate technology teachers' experiences in order to gain insight into their teaching practices involving CAD. A phenomenographic approach was used and twelve semi-structured interviews with lower secondary technology teachers were conducted. The interviews were analyzed and categories of description were hierarchically organized into the phenomenographic outcome space. The results show that teachers have different experiences of the intended learning outcomes when CAD is used in teaching, and four hierarchical categories emerged: (1) Handling the software, (2) Using ready-made models, (3) Manufacturing and creating printed models, and (4) Designing. The four categories describe teaching *to use* CAD and/or *through using* CAD. Further, the hierarchical categories indicate a teaching progression and the categories can be used as a basis for further discussions among teachers, teacher educators and researchers to develop CAD pedagogies within compulsory technology education.

Keywords CAD · Computer aided design · Digital design tools · Phenomenography · Technology education · Technology teachers

Introduction

Computer aided design (CAD) is a digital design tool that is used in many different domains for visualization and communication of artefacts and technological solutions, and today CAD is often part of technology education. By using CAD in technology education, teachers can combine design with a digital tool and thereby give pupils opportunities to develop skills in areas like communication and problem solving. These skills are important for developing technological knowledge and digital competence (cf. Carretero et al., 2017).

✉ Helen Brink
Helen.brink@kau.se

[1] Department of Educational Studies, Karlstad University, 651 88 Karlstad, Sweden

[2] Department of Environmental and Life Sciences, Karlstad University, 651 88 Karlstad, Sweden

Moreover, technology education syllabuses of many countries state that pupils should learn to develop technical solutions to different problems and communicate their ideas (e.g. NCCA, 2021; Finnish national agency for education, 2021; Ministry of New Zealand, 2017; Skolverket, 2011). CAD can be used as a tool to accomplish those syllabus goals.

However, when investigating research about technology education involving CAD, we found mostly studies concerning pupils' abilities to design with CAD activities and studies focusing on CAD pedagogies and learning within engineering and architectural programs (e.g. Cil & Pakdil, 2007; Garcia et al., 2007; Hodgson, 2008; McGarr & Seery, 2011; Garikano et al., 2019). Other contributions to previous research were in the area of informal education, often focusing on young children (e.g. Allan et al., 2018). However, when it comes to compulsory school and lower secondary technology education not very much is known about what is taught. Further, there is a lack of knowledge of teachers' intended learning outcomes (henceforth ILO and ILOs) in this stadium of education. ILO is what a teacher wants the pupils to learn (Marton, 2015) in a specific task or subject area. In order to fulfill the purposes and the objectives of the technology subject, teachers need to decide several ILOs, and design tasks with specific ILOs.

The current study is conducted in lower secondary technology education in Sweden. In Sweden, grade 1–9 is compulsory and the three last years (7–9) are part of lower secondary education, in which teachers are subject specialists often teaching 2–4 subjects. The Swedish school system syllabuses are built on core content for different year bands (Skolverket, 2011). For year 7–9 (lower secondary education, pupils at age 13–15) the core content for the subject Technology is grouped in the following themes: *Technological solutions*, *Working methods for developing technological solutions* and *Technology, man, society and the environment*. The syllabus also has knowledge requirements for the different year bands, and the teachers must translate and transform core contents and requirements into their own practice, hence the varying ILOs. In this translation, teachers have a lot of autonomy with little guidance from the steering documents. It is important to note that CAD is not mentioned in the core content or the knowledge requirements, but can be implied as a teaching activity for more overarching requirements. For instance, one core content is *How digital tools can provide support in technical development work, for example when producing drawings and simulations*, and the knowledge requirements related to this core content are *Pupils can carry out simple work…and also designing simple physical or digital models*. Another core content relevant for this study is *Different phases of technical development: identification of needs, investigating, proposing solutions, designing and testing. How different phases in the work process are interlinked.* These overarching examples of contents illustrate that every teacher needs to interpret the steering documents and transform them into more concrete ILOs. Therefore, a discrepancy between teachers' ILO and educational objectives formulated in a national level in the school system can occur. While developing ILOs, teachers can build on previous experiences of similar kinds (Marton, 2015). Little is known about what content, generic or specific, teachers find of central importance when CAD is taught at compulsory schooling. Without knowledge about the teaching practice when CAD is taught, we know little about the use of and intentions with CAD in compulsory school. With a better understanding of concrete teaching practices, we would also understand more about problem solving and communication using CAD, and about the technological knowledge and digital competence that pupils are given opportunities to acquire. To conclude, even though design and digital tools are an explicit part of several national curricula, more research about CAD in lower secondary school is needed.

To fill this gap, the focus of this study is on teachers' experiences of their practice when CAD is taught, specifically in terms of what content they choose. In the following, this teaching practice will be referred to as *teaching CAD* and the phenomenon of teaching CAD is framed by what the teachers describe that they teach and what they intend the pupils to learn. The phenomenographic approach and individual interviews were found suitable for investigating experiences of an underinvestigated phenomenon like this to reveal structural aspects of the participants' experiences. The results can contribute with important knowledge in this specific area of technology education.

Aim and research question

The aim of this study is to investigate the experiences of lower secondary school technology teachers in relation to *teaching CAD*, and identify the intended learning outcomes. By extension, implications of this study can support teachers' practices and hopefully facilitate pupils' learning. The following research question was formulated to guide the study:

What are lower secondary school technology teachers' experiences of teaching CAD?

The phenomenon *teaching CAD* was formulated broadly in order to make it possible to identify teachers' intentions without previous knowledge of their specific teaching practices.

Background

Design processes are at the core of technological education. Designing as an activity is important for an innovative society (Williams et al., 2012) and therefore, design and design processes are part of syllabuses in technology related subjects (e.g. technology, graphics, crafts) in several countries, for instance Ireland, Finland, New Zealand and Sweden (NCCA, 2021; Finnish national agency for education, 2021; Ministry of New Zealand, 2017; Skolverket, 2011). In the design process, technical problems can be solved and pupils can make models of their ideas and solutions. The models can be used for communication, visualization and documentation of solutions (Norström, 2013). Pupils can design and model digitally using a digital tool and visualize the model through a digital screen. A commonly used digital tool for designing in technology education is CAD.

There is a lack of research discussing CAD in the context of compulsory secondary technology education and we know little of what teachers do and what they intend pupils to learn when CAD is taught. However, we do know from a study of Brink et al. (2021) that one aim of technology teachers' teaching is to enable modelling using digital tools. Further, there is some previous research that describes teaching design and design processes (see the section *Design and design processes*), and since CAD is a digital tool that can be used for design, these findings can provide a good reference for this study. Research focusing on teaching CAD at other school levels than compulsory education, such as upper secondary technology education and university engineering programs, will also be used as a reference for this study. First however, the purpose of design and design processes in technology education will be discussed.

Design and design processes

When designing, technological problems are solved and products, artefacts or systems with a specific design are developed and documented through for instance a model. In that sense, design has similarities to problem solving and product development (Buckley et al., 2020). The two concepts, design and problem solving are often used in a similar manner and interchangeably in technology education settings (Gibson, 2008). Design processes are described differently based on various perspectives of different authors. For instance, Middleton (2005) describes the design process used in design and technology programmes in schools as follows: identifying a problem, undertaking research, developing solutions, producing solutions and evaluating solutions. Further, De Vries (2016) writes that design processes can be divided into three main parts: analysis, synthesis and evaluation. In the analysis phase, the problem is analyzed, in the synthesis phase, solutions for the problem are proposed and in the evaluation phase, the solution is assessed against objectives and criteria stated. Williams (2000) describes technology processes (like designing) comprising several activities like evaluation, communication, modelling, generating ideas, research, producing and documenting. The activities, parts or phases in design processes are iterative and repeating (Williams et al., 2012). Not all of these activities are used in every process, however (Williams, 2000).

In the design process, when pupils are in the phase of developing solutions, models and sketches can be used (Williams et al., 2012). Models can be designed digitally in a CAD program for physical and/or functional properties, or for intrinsic and/or intentional properties (de Vries, 2016; Nia & de Vries, 2017). The physical or intrinsic properties when designing refer to for instance size and form of the model, and the functional or intentional properties besides the function of the model also ethical and aesthetic aspects and ways of communication (de Vries, 2016; Nia & de Vries, 2017). There are several types of CAD software suitable for technology education in lower secondary school, for example TinkerCAD (www.tinkercad.com) and SketchUp (www.sketchup.com). In addition to the usefulness of modelling in terms of learning, the models created by the pupils also allow teachers to grasp pupils' technological knowledge (Elmer & Davies, 2000; Welch, 1998), a knowledge not easily expressed verbally (de Vries, 2016). In that way, the created models can be understood as a form of documentation and communication.

Teaching design and design processes

Ginestié (2018) describes two different types of teaching related to design processes; one closed type of teaching where the teacher guides the pupils through the problem, and one open type of teaching where the problem is presented to the pupils but no solutions are given. When teaching is open, pupils are encouraged to learn by discovery, and the exploration stage is important. While exploring, sketches are effective and important to find different solutions to the problem (Ginestié, 2018; Lane, 2018). A sketch can be a few lines on a paper or it can be a more developed drawing of something. Sketches are primarily used as support and a tool for the design process (Delahunty et al., 2020). In engineering graphics courses, teaching sketches is suggested to start the course, to improve the students' ability of visualization (Jerz, 2002). However, research shows that when pupils are presented with a technological problem, they often start constructing a solution directly, and few pupils start sketching (Welch, 1998). This approach results in serial solutions. If one idea is dismissed, pupils often start from the beginning with a new model without sketching. Similar findings are presented by Christensen et al. (2019) who state that novice designers in a middle school setting often start from their first idea, and design just one solution to a problem. The teaching is important for pupils' learning whether open or closed, and Elmer and Davies (2000) write that teachers to stimulate the learning process when pupils are designing and working with design processes, should be observing, initiating, participating, encouraging, maintaining and extending in their teaching approach. However, research indicate that teachers in middle school settings lack knowledge of design processes and therefor have difficulties teaching design processes (Christensen et al., 2019). So how teachers choose content, design lessons and act when teaching CAD can be a decisive factor for pupils' learning. This leads to the section *Teaching CAD* where findings from research from upper secondary and university levels are presented.

Teaching CAD

A CAD course can be organized in many different ways (Gelmez & Arkan, 2021; Gül, 2015). Traditionally, CAD pedagogies starts with teaching commands for pupils to be able to solve specific tasks (McGarr & Seery, 2011). This tradition is also used in post-primary schools, targeting on teaching how to use the software (McGarr & Seery, 2011). However, today, core contents of technology education are based on creativity and design and perhaps other methods for teaching CAD are better suited than a traditional pedagogy (Delahunty et al., 2020). Alternative CAD pedagogies are teaching how a CAD system works instead of teaching CAD through a specific task (Menary & Robinson, 2011). Chester (2007) argues that teaching to design in CAD requires several types of teaching; teaching that aims for declarative/procedural command knowledge and teaching that aims for strategic knowledge. Declarative knowledge is the general knowledge about the commands and algorithms within the software, as well as about understanding the commands and knowing what commands are available. Procedural knowledge concerns handling and executing the commands in the software and knowing when and how to use different commands. Strategic knowledge concerns how to create a design and how to make modifications, how to construct solids and surfaces, and how to easily change and choose between different modelling strategies. A pupil designing in CAD needs all types of knowledge described above. If one type of knowledge is underdeveloped, it will affect the pupil's ability to solve the task (Buckley et al., 2018). A recent study states that a CAD pedagogy containing telling-to-peers or writing-to-peers communication, enhance pupils' strategic knowledge and use of the software (Gelmez & Arkan, 2021). Further, Chester (2008) states that pupils will be better prepared for new CAD programs and updates in the software if the teaching focuses on strategic knowledge and allows pupils to acquire declarative/procedural knowledge meantime. Other research also questions whether traditional teaching (starting with declarative/procedural knowledge) is the most appropriate way to promote learning (Bhavnani et al., 2001; Garikano et al., 2019). Pupils need to acquire knowledge of how to create a model, but they should also be able to motivate the choices made in the creation of the design (Menary & Robinson, 2011). Moreover, introducing a new technology to a practice can entail challenges (Delahunty et al., 2020). Teachers need more than just declarative/procedural knowledge to be able to help pupils with their problems (McGarr & Seery, 2011). They also need to transfer procedural knowledge to other CAD software (Bhavnani et al., 2001). This is in line with other challenges with teaching CAD, for instance that CAD software are continuously changing (Gelmez & Arkan, 2021).

Further, research shows that many pupils get stuck learning the commands of the software instead of trying to find different solutions to the specific problem presented to them in a task (Chester, 2007; Leisney & Brandt-Pomares, 2015). This is problematic, since pupils may not develop adequate problem solving skills. Leisney and Brandt-Pomares (2015) also discuss how an early introduction of digital design tools can negatively affect the number of possible solutions to the task. A digital tool as CAD can enhance pupils' visualization and communication skills, but on the contrary, an early fixation in the design can limit other the possible solutions (Robertson & Radcliff, 2009). So, a result of letting pupils start designing digitally, is often a shallow form of learning due to the fact that they are dealing with double challenges, complex software and solving design problems (Chatoney & Laisney, 2019). Pupils who would like to explore different solutions to a problem must therefore quickly learn to operate the software (Charlesworth, 2007). A lack of software knowledge, or declarative/procedural knowledge (Chester, 2007), may otherwise lead to a great deal of time spent on presenting an idea instead of developing ideas.

Charlesworth (2007) adds that pupils working with digital design processes tend to work linearly, with fewer alternative solutions. However, when designing in CAD, more solutions to a problem can be developed if a pupil first begins to make sketches for the design (Delahunty et al., 2020). This is a result that Ginestié (2018) and Lane (2018) also found when pupils were solving problems, even though Ginestié (2018) and Lane's (2018) study concerned designing without a digital tool such as CAD.

With this background about teaching design and design processes and teaching CAD at other educational levels as a point of departure, it thus appears important to investigate how teaching concerning CAD is planned in relation to what the teachers intend the pupils to learn, in lower secondary technology education. There is a need for communicating what the pupils should learn when teaching CAD, before educating pupils and developing pedagogies for teaching CAD (Menary & Robinson, 2011).

Methodological framework—Phenomenography

The methodological framework in this study is the phenomenographic approach (Marton, 1981). The assumption in this approach is that a phenomenon can be experienced differently depending on one's previous experiences, positions and knowledge. In this tradition lies an interest in describing a phenomenon in the world as others see them, and in revealing and explaining the variations therein. In this study the phenomenon is *teaching CAD*. *Teaching CAD* is the teaching practice where CAD is taught and it is framed by what teachers describe is taught in this practice. What content do the teachers choose and what are their intentions with teaching this particular content in compulsory technology education? Moreover, a teaching practice is more than just the content. It also involves methods for how the content is taught. In this study, the methods used when CAD is taught are not part of the phenomenon *teaching CAD*. The methods used are peripheral, but provide a foundation for the phenomenon.

The phenomenon *teaching CAD* is described from a second order perspective, meaning that the focus is not descriptions of this teaching per se, but descriptions of the interviewees' experiences of it (Marton, 1981; Trigwell, 2006). Thus, we cannot say anything about what actually happens in the classroom, but we have reason to believe that what the teachers describe during the interviews is relevant for the teaching that the pupils encounter. Further, in the phenomenographic approach the different ways of experiencing a phenomenon are logically related to each other in a hierarchically organized outcome space, understood as categories of description. There is usually a limited number of experiences of a phenomenon (Rovio-Johansson & Ingerman, 2016). Therefore, a phenomenographic approach is suitable when the aim is to investigate how a group of teachers understand and teach a specific area where the content can be a mix of concepts, abilities and processes;

and where little is known about the teachers' intention with their teaching and the ILO. ILO will be used as a theoretical concept in this study and should be understood as what teachers intend pupils to learn when CAD is taught. In this study, qualitatively different experiences of the phenomenon teaching CAD have been identified during the analysis. Further, in the phenomenographic approach it is not relevant whose experience it is, rather the categories and their relations are of interest. Moreover, data collection continues until saturation, when new categories no longer arise when collecting new data.

Method

A phenomenographic approach has been used for analyzing the empirical data in parallel with collection of data through individual semi-structured interviews with technology teachers in order to reach saturation. The method of data collection used in this study will be explained, followed by a description of the analysis process.

Participants and data collection

During October 2018 and September 2019, the first author collected data for this study in Swedish compulsory school. Compulsory school in Sweden stretches from grade one to nine, and has mandatory technology education for every pupil in all grades. Lower secondary school is education from year 7 to 9, and pupils are aged 13 to 15 years. The subject teachers transform the national curricula core content into more specific intentional learning outcomes.

Twelve lower secondary teachers participated in the study and were chosen strategically to get a broad variation of experiences, rather than to compare groups of teachers (Alexandersson, 1994; Kvale & Brinkmann, 2014). Participants with different backgrounds, gender, teaching experiences and education were contacted. Contacts were established from three different networks; A medium-sized university, Swedish national center of technology education and from local teacher networks. However, it was important that the interviewees and the first author had not previously worked together to avoid implicit understandings, which may affect the results of the study (Kvale & Brinkmann, 2014). It was also important that the participating teachers teach CAD, or that they have previously taught CAD, to ensure that they have experiences to describe. The interviewed teachers, seven females and five males, have been teaching the technology subject for between 1 and 19 years. Some of the interviewed teachers work in a small school without colleagues in the same subject, and some of them work in larger schools with more technology teachers in service. All teachers have formal teacher education, but three of them lack diplomas of certification for teaching the technology subject. This is an expected division, since only about half of the in-service teachers teaching technology in lower secondary school have formal education for teaching the subject (Skolverket, 2019). Se Table 1 for further details.

Twelve semi-structured individual interviews were conducted with the twelve teachers. The interviews were held at the participating teacher's school and lasted for 35 to 60 min. During the interviews, the researcher asked open questions within this specific area of technology education to help frame the phenomenon of teaching CAD, and to make sure that different perspectives on the phenomenon were fully covered (Alexandersson, 1994; Kvale & Brinkmann, 2014). The questions were centered around digital modelling and what the teachers describe that they are teaching, see Table 2. However, the open questions also concerned

Table 1 Teachers participating in the study

Teacher	Length of Interview (minutes)	Diplomas of certification for teaching the technology subject	Teaching experiences in year	Number of technology teachers at the interviewees´ school
Teacher 1	37	No	1	3
Teacher 2	46	Yes	3	1
Teacher 3	58	No	7	1
Teacher 4	45	Yes	19	3
Teacher 5	46	Yes	18	3
Teacher 6	40	Yes	10	5
Teacher 7	39	Yes	8	3
Teacher 8	60	Yes	11	4
Teacher 9	59	No	5	1
Teacher 10	51	Yes	5	4
Teacher 11	35	Yes	12	4
Teacher 12	39	Yes	15	1
	Total length 555 min			

Table 2 Open and examples of complementary questions used during the semi-structured interviews

Question
Can you describe an example or assignment where pupils work with models or modelling using digital tools?
How did you choose your assignment?
What do you want the pupils to learn (from the chosen assignment)?
How do you explain the assignment to the pupils?
What are the technological areas in your assignment, when you are teaching digital models or digital modelling?
What programs or applications do you use?
What competences do you find important for you to have when teaching digital models or digital modelling?
How do you organize assignments with digital models and digital modelling in the classroom?
Examples of complementary question
Can you give more examples?
Can you clarify?
Can you tell me more?
What do you mean with …?
Can you describe that?
Can you develop that?
When you say … what … how …?
How do you concretize that?

how the teachers are teaching, with the aim to help the participants broaden and deepen their descriptions. The participants described their teaching in their own words and in ways they found necessary in order to explain it. However, complementary questions (see Table 2) were frequently asked, to elucidate the teachers' descriptions.

The interviews were recorded digitally and transcribed by the same researcher who conducted the interviews. The positionality of the interviewing researcher was to, in every step of the study, holding own experiences aside, not to bias the participants although there are interactions between the parties (Bengtsson, 2013).

Analysis

The analysis process started with listening to the recorded audio files and reading the transcriptions. This listening and reading were iterative and in parallel with the interviews to establish a holistic view of the data material. At the same time, the search for extracts pertinent to the phenomenon started. Usually, tentative categories can be established early during the data collection (Marton & Booth, 1997), as in this study. The first tentative categories were formed around teaching commands in the software and the use of 3D printers to make physical objects.

The analysis process continued with extracting units of description from the transcripts, as significant words or expressions used by the teachers showing the same thing or concerning the same content. Similar words or sentences were coded. These units of descriptions were grouped in different constellations to find similarities and differences between them. One example of correlation is when two different teachers describe how they explain to pupils that models designed in CAD need to be attached to each other for the 3D printers to be able to print the model correctly. The two teachers describe this differently but the interpretive meanings are similar, and the units are therefore grouped together. The extraction of units of descriptions was ongoing during the interviews and more units of description were found and grouped continuously. After nine interviews the groups were stable and the units of descriptions were categorized. Three more interviews were conducted to found out if the data material had reached saturation, but they gave no further information, and no new units of descriptions or categories were identified. The differences between the units of description constitute the demarcations between the categories. The first author grouped the units into categories but all three authors discussed and modified the categories together during the analysis process before the resulting categories were final.

The outcome space, the categories of experience in relation to teaching CAD, comprises descriptions of various content, identified as ILO, the what-aspect of the teaching. The hierarchical structure of the categories is based on ILO. The first category holds one dimension of variation of ILO, the second category adds on more variations of ILO, building up a more developed category, and so on. Some of the variations are described as simultaneously understood and co-existing by the teachers. They do not separate them from each other. Within a category, these variations experienced simultaneously constitute a set of variation, even though they are analytically separated. The categories and the hierarchy will be further explained in the *Results* section.

Results

The aim of this paper is to investigate technology teachers' experiences of teaching CAD, and four categories have emerged. This section starts with describing the four categories and the ILO in each specific category respectively, starting with the least developed category, thereafter explaining the hierarchical structure. The resulting categories are:

(1) Handling the software
(2) Using ready-made models
(3) Manufacturing and creating printed models
(4) Designing

Each category is presented with a detailed description of the ILO and how the teaching is conducted according to the interviewed teacher. Excerpts showing content and methods are provided in relation to the categories to validate the results and to exemplify and explain the variations within the different categories.

Handling the software

The experiences of teaching CAD in this category relate to handling the software. The ILO when teaching CAD described in this category holds just a few variations; to introduce the software to the pupils and to teach the pupils basic commands, functions and symbols. The teachers describe that they want the pupils to be acquainted with the software and that they can try it out.

> Oh, the seventh graders are doing key chains. The task is actually to be acquainted with design tools. (Teacher 8)

The interviewed teachers give examples of experiences explaining that they introduce CAD at a very basic level. The teachers show pupils simple commands, symbols and functions of the software in question. The teachers explain that the digital models that pupils create using CAD are simple and have distinct geometric shapes. Teacher 2 puts it as follows:

> And that you kind of understand things about shapes and how you can rotate them. […] They get to try to just simply make a cone, make a box. They can pull it out, expand it and trim it. […] And much is about handling the software. That you understand how to use short commands. […] And in TinkerCAD [digital design tool], how you turn different objects around, so you get, this is a cone, but now it is turned upside down. It is still a cone. Same thing but upside down. (Teacher 2)

Jewelry or name tags are common objects for beginning to learn CAD. What is designed is not important in this category, according to the interviewed teachers, since the ILO is to learn to handle the software. When pupils create these objects, they use basic geometries from the software toolbar and combine them into their own objects. One teacher describes teaching as based on the idea that the pupils have to be allowed to play around in the digital design tool.

> So they should be able to klick and play, you can call it that, and learn the program. (Teacher 7)

In this category, teachers sometimes show what they are doing by connecting a projector to their own computer in the classroom, and the pupils follow the instructions and copy what the teacher is doing. An alternative is to use YouTube tutorials, and let the pupils copy and emulate what the YouTube clip shows.

Using ready-made models

In this category, the experiences of teaching CAD relate not only to handling the software, but also to using ready-made models (in the software). The ILOs in this second category is based on the ILO from the first category and more variations are added. One added ILO is part of the design process, developing solutions (Middleton, 2005). Pupils can understand how models are created and the interviewed teachers express that pupils discover the difficulties involved in making advanced models on their own. However, the teachers describe that they want to show the pupils the possibilities of CAD and that most models in fact are based on basic geometrical forms. The second added ILO is that digital objects and models can be a sort of documentation, a modern blueprint.

In this category, pupils are allowed to freely explore the software. Pupils are encouraged to search for models made by others for inspiration. The interviewed teachers say that pupils can use ready-made models collected from databases, galleries and libraries connected to the software. By fetching ready-made models, pupils get opportunities to see what is possible to create and design digitally. Teacher 1 describes how pupils use these galleries.

> TinkerCAD has a very good gallery, where you can enter and look around. […] They [the pupils] like to go in there and look. They often take things from there. (Teacher 1)

Teacher 2 talks about these galleries in a similar manner.

> Yes, you can search and find. It is like an open community. There you can see someone who have built a robot with ninja swords and you think this is awesome, I would also want to do that. Then you discover that it is about basic forms. You work with cubes and diamonds, and things. Someone has put those forms together to a robot. (Teacher 2)

According to the teachers, neither tutorials nor YouTube clips are used so much in this teaching since pupils already know some beginner commands in the software. Pupils explore the galleries on their own and design models according to their own ideas. What is designed is not important in this category, just like in the first category, according to the interviews.

Manufacturing and creating printed models

The third category, manufacturing and creating printed models, is even more developed. It includes the first category, as well as parts of the second category, handling the software and documentation. The ILOs in this third category is to make the pupils understand a different part of the design process than in the second category; to manufacture and create printed models i.e. producing solutions according to Middleton (2005). In the interviews, the teachers point out that it is important that the pupils understand the principles of how a 3D printer works, that the printer fabricates objects one layer at a time and cannot start printing from surfaces that are not supported from below. The following excerpt shows how Teacher 3 explains the principles to the pupils and also that the printed model per se is not important.

> But otherwise, the task is open. And you cannot print this thing because it [the printer] will be printing a little bit here and then move and print more there, then move again, and well, yes. I think they understand the principles. (Teacher 3)

In this third category, as in category 1 and 2, the task and what is designed are not decided beforehand by the teachers and pupils can choose what to model based on their own preferences.

> So, the task hasn't been more controlled than that. Now I should do something in TinkerCAD that can be printed. (Teacher 3)

In this category, interviewed teachers express that the 3D printer can be used as a modern manufacturing method, since 3D printing is a fast way to produce a physical model. The interviewed teachers want to expose the printed physical model as a means in the iterative design process and as a physical documentation. But the physical printed model can also be an end, a complete object ready to use. In those cases, it is not necessarily the pupils themselves who have designed the models. The pupils are allowed to fetch and print ready-made models from digital libraries and databases.

The pupils are not always given the opportunity to print their models, since the focus is on the 3D printing method itself. Teaching is about the manufacturing method. Printing models is time-consuming in a school context, and according to the interviewed teachers, problems tend to occur when pupils are allowed to use the printer by themselves, which is why this is not always allowed. Teacher 12 discusses this problem in the following excerpt.

> But sometimes you have started something [a print], and they [the pupils] have come in groups and just looked at how it works. And then the printer has been printing when you are not present. (Teacher 12)

Teachers with experiences in this category explain 3D printing principles through telling the pupils about props and supports and showing them printed models which have not been supported so that the thermoplastics, the filaments, are suspended midair. Teacher 3 gives an example of a printed car that was not successfully designed for printing.

> I have explained [to the pupils] that it [the 3D-printer] cannot start printing in the air. If so, the threads will be hanging. (Teacher 3)

This teacher told that this failed car is often shown in teaching situations to demonstrate to the pupils the principles of the 3D printer and what will happen if models are not correctly designed in the CAD software.

Designing

Experiences related to the fourth and most developed category concern designing. This category also includes experiences from the three previous categories. When teaching CAD according to experiences related to this category, ILOs are parts of the design process, to design strategically in CAD and to create surfaces and solids efficiently. ILOs from previous categories are included. To design strategically, the interviewed teachers with experiences referred to this category explain that pupils have to learn more advanced commands and functions in the software. They practice working with different planes and depths as well as various axes in a three-dimensional coordinate system.

The interviewed teachers describe experiences of teaching the pupils that all parts in a model, for instance the letters that make up the text of a key tab, have to be linked to constitute a unit. If the parts are not linked, a 3D-printer will not be able to print the object, even if it looks correct on the screen. In this category, the model to print is in focus, not the printer per se.

> There are so many steps when you model an object. So, there cannot be a gap between the legs of the chair and the chair. Or the key tab, it happens often, the letters are wrong, they are not attached to the tab. (Teacher 8)

The interviewed teachers also give examples of experiences pointing out that they teach how to create models by removing surfaces and solids instead of building something. For instance, one teacher describes how pupils are given the task to design a house, and the teacher wants the pupils to start out from a cuboid and then cut out smaller cuboids to create rooms, windows, and doors.

> … and they will design a house, it is a completely different way of thinking. In SketchUp [digital design tool] you drag in a box or a cuboid. And that box, well there you remove the kitchen. To make a kitchen, you need to take off something. (Teacher 8)

To experience teaching CAD as in this category *Designing* is a question of making a model in accordance with objective criteria and specifications, a best practice of modelling. Some examples mentioned during the interviews are if the model has the correct measurements (has the right scale been used?) and if the desired function is achieved (will the door in the room open the right way?). Moreover, problem solving is also mentioned during the interviews as finding different ways to handle the software to achieve a certain desired feature for the model. A solution to this problem is for instance when pupils find a YouTube clip that describes how to make the wanted feature. Pupils copy and emulate the instructions from the clip. Teacher 9 gives an example:

> So they [the pupils] copy tutorials, watch, how did they do it. They have searched, they are aware of the problem and they have found a solution to the problem. (Teacher 9)

In this category of experiences, teaching is often adapted to each individual, and the teachers give examples showing that a great deal of the pupils' work is done on their own terms. The pupils are allowed to explore the software independently, and freely select a model to be designed, as in the previous categories. The teachers taking part in the study experience that they teach strategies of digital design in CAD, how pupils can effectively create digital models that allow for adjustments and changes. Sometimes teachers allow the pupils to remodel fetched objects. They explain that just fetching an object (or model) is not so difficult and they want pupils to learn to use different commands in the software to be able to make changes and adjustments in the models.

> Well, I say that you can take a ready-made object, if you change it, so it becomes your own. (Teacher 1)

The teaching, according to the interviewed teachers' experiences, focuses on pupils doing and redoing, changing, adjusting, and trying out different alternatives and options. When results are not as expected, pupils are encouraged to find solutions on their own or together with peers. According to the interviewed teachers, pupils turn to each other when they need help with the CAD software. Sometimes, pupils can be assistant teachers.

Hierarchical structure

The results show four different categories of experiences of teaching CAD. The categories are the result of the various ILOs. The variations of ILO are sometimes to be seen as a set of variation where different ILOs are co-existing and simultaneously understood by the teachers. One example is in category 2, when developing solutions using a CAD software constitutes documentation at the same time. The categories are hierarchically organized from a less complex category (1) with one ILO, to a more complex category (4) with more variations or sets of variations in the ILOs. A summary of the outcome space of teachers' experiences of teaching CAD and the (sets of) variations of ILOs is presented in Table 3, where also examples of teaching content are shown.

The hierarchical structure of the categories can be further explained visually and is shown in Fig. 1. Category 1 is the middle circle in white, holding one variation. The ILO from the first category is included in category 2 (light gray). ILOs from category 2 are included in category 3 (middle gray), and so on. However, there is one exception. The ILO "developing solutions" from category 2 is not included in category 3, but is then again included in category 4 (dark gray). All the other ILOs are a part of the next category.

Discussion

In this section, findings from the categories and the hierarchical structure are discussed and a teaching progression based on the categories is presented. Relating to Middleton's (2005) description of the design process, we can see that the outcome space in this study relates to different parts of the design process and no experiences relate to the process as a whole. The four categories with different ILOs constitute two different main objectives; teaching *to use* CAD and teaching *through using* CAD. Teaching *to use* CAD concerns ILO connected to teaching about how to use the software as in category 1 and partly in category 4, relating to declarative/procedural knowledge (Chester, 2007). Teaching *through using* CAD concerns ILOs where the CAD software is used as a tool for other outcomes connected to design processes (de Vries, 2016; Middleton, 2005) and technology processes (Williams, 2000), such as the iterative cycle, documentation, developing, producing and evaluating solutions to a problem (category 2–4).

From a teaching point of view, the hierarchical structure (Fig. 1) can also be understood as a teaching progression, here represented with arrows in Fig. 2. Based on the four categories of experiences of teaching CAD, we can conclude that teaching starts with the ILO from the first category and continues with three possible paths shown in Fig. 2. The different possible paths are;

Handling the software.

Handling the software → Using ready-made models.

Handling the software → Manufacturing and creating printed models.

Handling the software → Designing.

Table 3 Summary of the resulting categories of teaching CAD

Outcome space	ILO of teaching CAD	Examples of content when teaching CAD
(1) Handling the software	Basic handling of the software	Basic commands, functions and symbols
(2) Using ready-made models	Basic handling of the software Developing solutions Documentation	Create objects digitally from basic geometrical forms. Digital documentation
(3) Manufacturing and creating printed models	Basic handling of the software Producing solutions Iterative cycle Documentation	Create printed objects 3D printer as a manufacturing method Printed objects as a means in an iterative cycle Digital and physical documentation
(4) Designing	Basic handling of the software Advanced handling of the software Developing solutions Producing solutions Evaluating solutions Iterative cycle Documentation	More advanced commands, functions and symbols Strategically create digital models Design models to print Design in accordance with objective criteria Try out different alternatives and options

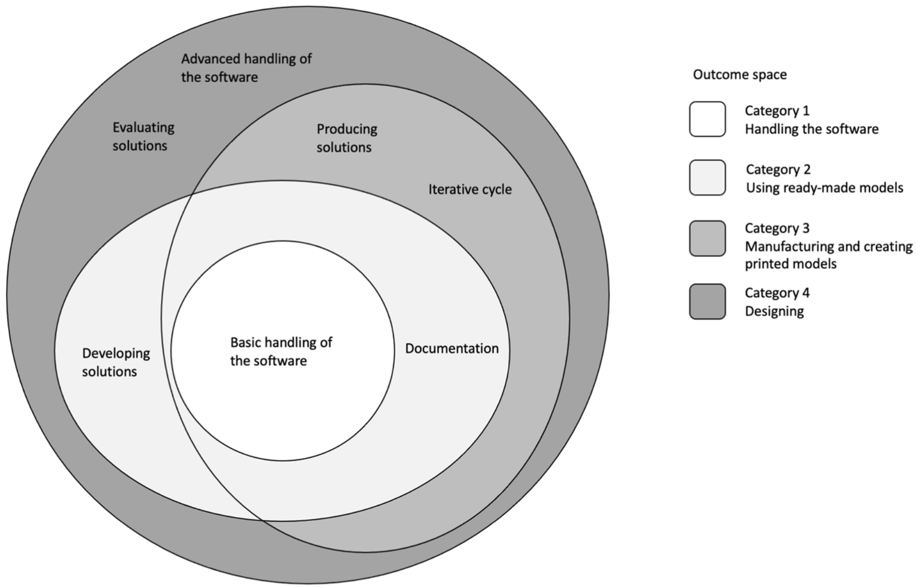

Fig. 1 Hierarchical structure of the categories of teachers' experiences of teaching CAD

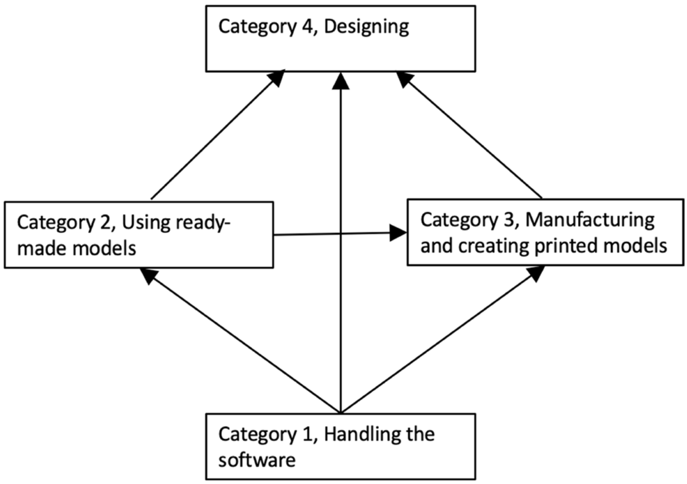

Fig. 2 Teaching progression of teachers' experiences of teaching CAD

Handling the software → Using ready-made models → Manufacturing and creating printed models.

Handling the software → Using ready-made models → Designing.

Handling the software → Manufacturing and creating printed models → Designing.

Handling the software → Using ready-made models → Manufacturing and creating printed models → Designing.

Depending on which path teaching takes, pupils are given different opportunities to learn various content, since the ILOs differ. The teaching that involves the most variations of ILOs is when all four categories are included. However, teaching CAD does not always end with category 4, according to this study. Teaching can end after each one of the four categories. The teaching progression is the authors' contribution for explaining the hierarchical structure.

Having established two main objectives and a teaching progression, the discussion continues with delineating each category in more depth.

The first category, *Handling the software*, holds just one ILO shown in Table 3. The interviewed teachers express that this teaching is limited to a basic level and that pupils' ability to design is not so developed. Teaching CAD according to the first category can be compared to and equated with what Chester (2007) would call teaching declarative/procedural knowledge, hence teaching *to use* CAD. The teaching progression discussed earlier, starting with teaching according to experiences included in category 1, is on the contrary in line with research suggesting that teaching should start with strategic knowledge (as in category 4) and allow pupils to learn declarative/procedural knowledge meanwhile (Bhavnani et al., 2001; Chester, 2008; Garikano et al., 2019). Further, if the teaching ends after category 1, pupils can learn a digital tool, but they are not likely given opportunities to apply the tool on technological problems to be solved, or learn something about design processes. Consequently, the teaching progression needs further attention in lower secondary technology education. Moreover, teachers often demonstrate and guide pupils with instructions to follow when teaching according to this first category. Pupils can also be guided by YouTube clips when they learn commands and functions in the software. Ginestié (2018) described a closed form of teaching as when teachers guide pupils through a problem in design processes. In the present study it was found that guiding through a software problem, as in this category, can also be interpreted as closed teaching.

In the second category, *Using ready-made models,* the experiences of teaching CAD refer to ILOs based on the first category, though other variations are added. CAD is used to teach parts of the design process by using ready-made objects, in other words this is teaching *through using* CAD. The understanding of adjustments of objects is important for pupils to be able to develop solutions to a design problem on their own, according to the results. Using ready-made objects is also one way to speed up the design process, because the pupils do not need to start from the beginning every time they design something. Another ILO in this category is to make documentations of the designed model, and experiences in this category find CAD a good tool for communicating technology as Williams (2000) describe in technology processes. Hence, pupils are given opportunities to develop technological knowledge and digital competence of the kind seen as important by Carretero et al. (2017) and Norström (2013).

In teaching CAD according to the experiences relating to category 3, *Manufacturing and creating printed models*, new and more variations than in the first and second category are added and CAD is used as a means for teaching parts of the design process, hence teaching *through using* CAD. ILOs focus on 3D printers and 3D printed objects, and the fact that design processes are iterative (de Vries, 2016; Middleton, 2005; Williams et al., 2012). The 3D printed model is often an end to the task in CAD according to the results of this study, a result Charlesworth (2007) also observed. On the contrary, while teaching about 3D printing as a manufacturing method, pupils are given insights into the iterative cycle of design processes according to the interviewed teachers (cf. Middleton, 2005). However, research shows that access to a printed physical model, and the opportunity to reprint a model, can help pupils' understanding of design processes, problem solving and product development (Dickson et al., 2020; Novak & Wisdom, 2018). However, the results in this category do not show teaching where pupils can print several times and redesign their models after printing.

Teaching CAD as experienced in category 4, *Designing*, the ILOs can be considered as both teaching *to use* CAD and teaching *through using* CAD. ILOs could be to design strategically and solve problems efficiently, using a digital design tool, be parts of the design process, developing solutions, producing solutions (in those cases when teaching allows 3D printing) and evaluating solutions (cf. Middleton, 2005). The problems to be solved, mentioned by the teachers mostly concern procedural and designing strategies in the software (Chester, 2007). Most of the time, however, teachers describe that they encourage pupils to learn more commands on their own. However, there are some examples of teaching other problems, more focused on functional aspects in the designed model, like door openings, or having all parts of the model attached to each other. These two aspects of design, the physical and functional aspect (de Vries, 2016) or the intrinsic and intentional nature of models (Nia & de Vries, 2017) are not distinguished or made explicit when the teachers describe their experiences of the pupils' efforts to design a model digitally. However, when ILOs in category 4 do focus on functional aspects in the designed model, pupils can redesign the model if the result is not as expected. The teachers present a task, for instance "design the house of your dreams", and the pupils are then free to examine and try different alternatives and options when designing. This is an example of open teaching (Ginestié, 2018) which allows for a great deal of discovery and exploration.

From the four categories we can conclude that different pupils most likely will be provided with different content depending on the teacher's experiences of teaching CAD. As was stated in the *Background* section, Swedish technology teachers have great autonomy when it comes to interpreting the syllabus and transforming the core content to ILO, hence ILOs can differ from teacher to teacher. The pupils are given different prerequisites to learn different contents, and it is not clear what content teaching CAD has or should have in compulsory school. Some teachers teach for instance problem solving and digital competence to a greater extent than other teachers, according to the results of this study, depending on which path the teaching takes in the teaching progression (Fig. 2). The design process is also given different levels of attention depending on the path taken, but not one of the paths teaches the design process as a whole as described by for instance Middleton (2005) or de Vries (2016). The best opportunity to learn most about design as a process is afforded when experiences of all four categories are included in the teaching.

Teaching CAD necessarily involves some aspect of problem solving using digital tools. Problem solving is an important competence in contemporary society (Carretero et al., 2017), and some examples of problems when teaching CAD concern handling the software, or problems about how to create simple functions in the designed models. The problems that address handling the software are a new type of problems in technology education, not to be found before the digital tools entered. Problems occur due to the digital tool. Without the digital tool, these problems would not exist. In other words, new technology introduces new problems that need to be solved.

Further, design problems can be solved using hand-made sketches (Delahunty et al., 2020; Ginestié, 2018; Jerz, 2002; Lane, 2018), and models can thereafter be created in CAD. However, this is not something the interviewed teachers mention that they teach, when they talk about their experiences of teaching CAD in this study, though the ability to sketch can be an important help for pupils when solving problems (Delahunty et al., 2020; Ginestié, 2018; Jerz, 2002; Lane, 2018). According to the results, it is not apparent that teaching CAD concerns *identifying problems* or *undertaking research* to find solutions to a problem (Middleton, 2005). This could be compared to the core content in the Swedish technology syllabus, describing teaching different phases of technical development as identification of needs and investigation (Skolverket, 2011). The absence of *identifying problems* or *undertaking research* could be why the design intent is not obvious in the area of teaching CAD in lower secondary technology education, even though strategic modelling is apparent in one of the resulting categories. It is clear, however, that the practice of teaching CAD at the lower secondary level differs, taking sketches and design intent as examples, from teaching CAD at the upper secondary and university levels. This is why research related to this specific level of education is needed.

The results from this study show four categories with various ILOs when CAD is taught and where pupils can develop digital competence with help of this tool. ILOs are formed around two main objectives; *to use* CAD, where the software is in focus, and *through using* CAD, where parts of the design process are in focus. The results show that teaching *to use* CAD can be one way to fulfill the core content of *How digital tools can provide support in technical development work* (Skolverket, 2011) and teaching *through using* CAD can support pupils when *designing simple digital models* (Skolverket, 2011).

Conclusions and implications

The categories and the variations of ILO, as found in this study, can open up new dimensions of teaching CAD and broaden teachers' understanding. From the categories can be concluded that technology education differs a great deal between different teachers. Moreover, there is a lack of a common understanding among technology teachers regarding what the pupils should learn, shown in the four resulting categories. These differences can be explained in terms of the different experiences of teaching CAD. Some pupils are taught to handle the CAD software as an isolated task. Other pupils are taught part or parts of design processes with CAD as a digital tool. These differences need to be elucidated and discussed on the basis of the overall aims of the technology subject, the core contents and on the basis of what technological and digital competence pupils should have acquired when they finish compulsory school. We know from the results of this study, that pupils through teaching CAD can develop communication and problem solving skills, skills that are important for digital competence (cf. Carretero et al., 2017). From the results of this study, we suggest that if technology teachers want to teach about design, problem solving and design processes, teaching should include category 4, *Designing*. In other words, CAD should then be used as a tool for designing, as a means and not as an end.

Further, CAD is a relatively new element in compulsory school, as stated earlier. However, there are a great many activities like maker spaces or fab-labs young people can join in their spare time. In these settings, tinkering and creatively making things are encouraged. Digital modelling and 3D printers are frequently used. If pupils attending the compulsory technology education already know how to make models using a CAD program, changes in this teaching will probably occur due to that fact. How do teachers prepare for this development? Another issue for technology teachers in lower secondary school is if CAD is introduced in earlier years, grade 1–6. How should the teaching progression then be organized? We know little about these developments today but it is important to start preparing for this possible future. In discussions like that, this article can contribute with knowledge about the ILOs when CAD is taught.

Some implications for teaching CAD at the level of lower secondary school are that if teaching starts with handling the software, teaching *to use* CAD, pupils can evade double challenges like complex software problems and design problems. However, starting with the opposite, with teaching design problems *through using* CAD, commands, symbols and functions can perhaps be learnt along the way (Chester, 2008; Garikano et al., 2019). Further, if a teacher wants to enhance pupils' problem-solving skills, they can include sketches and printed models to a greater extent when working with design processes. Teaching can also allow pupils to redesign, remodel and reprint the models several times to enhance their problem solving skills.

Some questions still need to be answered to get a more holistic understanding of technology education, specifically teaching CAD. Focusing on teachers' experiences gives us no insight into the pupils' learning. This shortcoming can be remedied in future studies. The enacted teaching can be studied and forthcoming research can for instance investigate how teaching can be structured and organized to enhance learning *to use* CAD and learning *through using* CAD. The ability to sketch is important in higher graphical and technology education for problem solving (Delahunty et al., 2020; Ginestié, 2018; Jerz, 2002; Lane, 2018) and the absence of sketches in lower secondary school, and the effects of that for pupils continuing to higher education, can be further investigated.

This study was conducted in Swedish compulsory lower secondary school and syllabuses and objectives in technology related subjects in other countries are not exactly the same. However, the results from this study can be transferred to other contexts, due to the fact that design and design processes are a prominent core content in technology related subjects in many countries and that CAD software can be used in this education. Further, what a teacher says that he or she teach, may not correspond with the enacted teaching (Bengtsson, 2013). The intention of this study was not to investigate the enacted teaching, however, there are reasons to believe that teachers' experiences of his or her teaching influences the enacted teaching.

This study is a contribution to a common knowledge base for technology teachers, teacher educators and researchers interested in technology education. The resulting hierarchical categories can help teachers clarify their intentions when CAD is taught and help develop the pedagogy for the chosen content.

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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