Designing teaching—teaching designing: Teacher's guidance in a virtual design studio

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Abstract
This study examined pedagogical aspects of virtual designing. It focused on how an industrial design teacher organised a university course in plastic product design and how the teacher guided student teams' design processes in a virtual design studio. The model of Learning by Collaborative Design was used as a pedagogical and analytical framework. The study employed qualitative content analysis of the teacher's notes posted to the Moodle database. The results indicated that teaching exhibited three characteristic approaches: problem-driven, solution-driven and procedural-driven. The teacher's notes were predominantly solution-driven statements, including new information, design ideas and evaluating design. The present results demonstrate the link between the model of Learning by Collaborative Design and the three teaching approaches.

Keywords
Collaborative design, computer supported design, design education, design process, industrial design.

Introduction

In design education, students more and more often encounter virtual learning environments (Maher, Simoff, & Cicognani, 2000; Wang, 2009) and their learning to use modern digital design tools has become crucial within design practice (Al-Doy & Evans, 2011; Yang, You, & Chen, 2005). A virtual learning environment offers opportunities for design students to participate in multidisciplinary collaborative projects and provides them with the experience of global professional practices (Karakaya & Şenyapılı, 2008).

The term, *virtual learning environment,* refers to an asynchronous web-based setting that provides tools for collaborators to share conceptual and visual design ideas as well as a medium for their joint construction of the design object (Karakaya & Şenyapılı, 2008; McCormick, 2004). A typical virtual learning environment provides tools for computer-mediated communications (e.g., e-mail, chat, and threaded discussion forum) and tools for course administration. A more elaborate virtual design studio (VDS) may consist of sophisticated digital design tools supporting various virtual representations, 3-D modelling and rapid-prototyping (Evans, Wallace, Cheshire, & Sener, 2005; Oxman, 2008).

Researchers and educators have addressed the need to integrate computer and IT-based capabilities in design education and *pedagogical* aspects of virtual designing are beginning to receive more attention (e.g., Kvan, 2001; Oxman, 2008; Wang, 2009). Yet many studies of virtual design focus on technological challenges (e.g., Al-Doy & Evans, 2011; Charlesworth, 2007) or on collaborative issues among participants (e.g., Karakaya & Şenyapılı, 2008). Hence we have seen a need for further research focussed specifically on the pedagogical issues related to virtual designing in a higher-education context.

In this study, we investigate an industrial design teacher's orchestration of participants' efforts in a VDS setting at four Finnish universities, and we explore the nature of teaching by analysing what kind of guidance the teacher provided during the virtual design process. "Orchestration" refers to the planning, management and guidance of designing (see Littleton, Scanlon, & Sharples, 2012). In the following, we briefly review the characteristics of design knowledge and teaching. Finally, the implications of our results for virtual designing in educational settings are set out.

Characteristics of design knowing and teaching

Designing is considered to be a complex and iterative problem solving process. Design solutions emerge gradually in the process of structuring and restructuring a problem, defining and redefining constraints on designing, and generating and testing solutions (Cross, 2006; Goel, 1995). In other words, one may construe designing as moving back and forth between a problem space and a solution space (Dorst & Cross, 2001; Goel, 1995).

The design space forms the external frame to designing. The set of possible acts is usually so vast that the designer is able to study only a part of that space within a realistic time. By paying attention to constraints, the designer can ensure that the design will exhibit the required and most desirable properties. Knowledge related to external constraints defines relations between the product to be designed and its environment and conditions (Goel, 1995; Visser, 2006) and that knowledge is typically displayed by experts. Research findings on expertise in design (Cross, 2004) indicate that novices tend to generate problem solutions without engaging in extensive structuring of the problem and analysing of external design constraints. Experts, by contrast, focus on analysing and structuring the problem and design constraints before proposing solutions.

Kruger and Cross (2006) identified four types of cognitive strategies employed by the designers they investigated: (a) problem-driven, (b) solution-driven, (c) information-driven, and (d) knowledge-driven. A given designer generally adopts an approach based on a strong preference for one of these four. Problem-driven designers focus on defining the problem and using information that is strictly needed to solve the problem whereas solution-driven designers focus on generating solutions. Information-driven designers focus on gathering information from external sources and develop a solution on the basis of that information. Knowledge-driven designers focus on developing a solution on the basis of their prior knowledge. Kruger and Cross's (2006) protocol study of nine industrial designers revealed that most of these designers employed either a problem-driven or a solution-driven design strategy, and further, a problem-driven strategy tended to produce the best results according to the assessed aspects of quality. Yet, interestingly, Sagun and Demirkan (2009) found that in a design studio setting, the critiques of the collaborators referred more to the solution space than to the problem space.

For several decades, it has been common to develop theoretical models of design processes in order to understand and improve professional design activity. The idea of design as an iterative (i.e., spiral and cyclic) process has been used to illustrate how various activities in design fit together. According to Visser (2009), there are significant similarities (and some differences) among the design activities implemented in various situations. The process-related activities consist of organising the design process (time scale, individual versus collective design) and tools in use. Visser (2009) emphasised that the way designers organise their on-going task shapes their activity. The organisation of one's work is thus a kind of tool which structures and guides design activity.

Communication among individuals in a socially distributed system is always conducted in terms of a set of mediating artefacts (Hutchins, 1995). In the collaborative design process, the mediating artefacts can be divided into two kinds: procedural and design (Perry & Sanderson, 1998; see also Visser, 2006). The former artefacts are related to structuring and organising the collaborative design process whereas the latter are related to designing the product itself. Design artefacts vary from material to digital representations (Charlesworth, 2007; Pei, Campbell, & Evans, 2010). In design education, it is important for students to have opportunities to use digital tools and to simulate collaborative professional design practices (Cardella, Atman, & Adams, 2006; Chen & You, 2010; Karakaya & Şenyapılı, 2008). At the same time, it is crucial for design educators to focus on the pedagogical approaches to providing guidance and facilitating collaborative designing in the VDS setting.

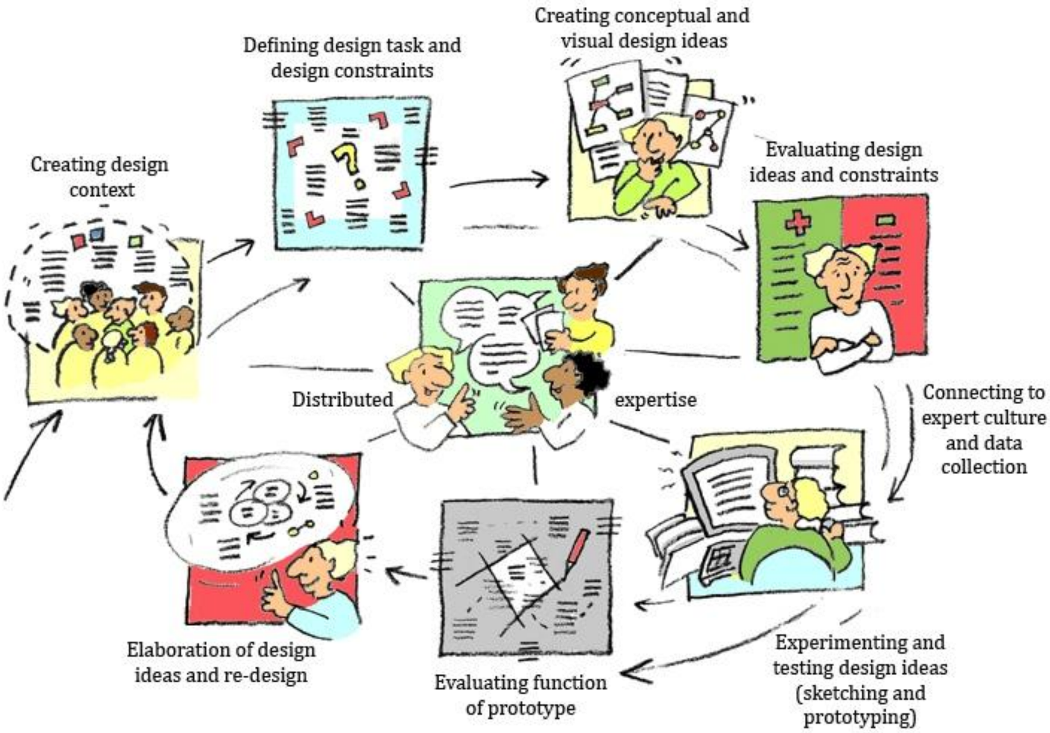

Figure 1. The model of Learning by Collaborative Designing (LCD)

The pedagogical models that have been widely adopted in design education are studio-based teaching (Schön, 1987; Waks, 2001), problem-based learning (Eilouti, 2007), and project-based learning (Lee, 2009). Further, several educators have stated that collaborative inquiry-based teaching and learning, particularly when supported with technology, appear to be most promising ways to achieve the desired changes in teaching and learning practices (Dillenbourg, Järvelä, & Fischer, 2009; Littleton, Scanlon, & Sharples, 2012).

The idea behind collaborative designing, as considered here, derives from the model of Learning by Collaborative Designing (LCD; see Figure 1) developed by the authors (Seitamaa-Hakkarainen, Lahti, & Hakkarainen, 2005; Seitamaa-Hakkarainen, Viilo, & Hakkarainen, 2010). LCD is a pedagogical model that has been developed to guide and facilitate students' collaborative design processes in technology-enhanced learning. The model emphasises open-ended design tasks and collaborative interaction within and between teams, between students and the teacher. In a design course, students are concerned with the usefulness, adequacy, improvability, and developmental potential of design ideas (Seitamaa-Hakkarainen, Viilo, & Hakkarainen, 2010) and develop knowledge and skills to model, design and construct ideas into physical artefacts (Al-Doy & Evans, 2011).

Aims and objectives of the study

The overall aim of the study described here was to examine the pedagogical aspects of virtual designing; we wished to investigate the teacher's orchestration of design learning. In order to get an overview of the teacher's contributions in a VDS setting, the first objective was to examine the nature of communication in VDS. Thus, the first research question was: *How was the communication of the teacher and of students linked in VDS?*

The second objective of the study was to analyse teaching in VDS. The second and third research questions of the study were:

- *What kind of guidance, based on the model of LCD, was provided by the teacher during the virtual design process?*
- *What was the distribution between the three teaching approaches (problem-driven, solution-driven and procedural-driven guidance)?*

Method

Setting and participants

The research setting was provided by the Development Project for Plastic Product Design whose general aim was to develop virtual learning materials and to develop a basic course in plastic product design for industrial design students. The participants of the study consisted of a teacher from the University of Art and Design in Helsinki (now, Aalto University), tutors (*n*=4) and students (*n*=53) from four Finnish Universities. The teacher had twenty years' experience in industrial design, specialising in plastic products, but did not have extensive teaching experience.

The students (*n*=53) participated in the course at their respective institutes: the University of Art and Design in Helsinki (*n*=17), the University of Lapland (*n*=18), Tampere University of Technology (*n*=4) and Lahti University of Applied Sciences (*n*=14). The majority of the students were specialising in industrial design. They made up 17 design teams (referred to as Team 1 to Team 17) composed of three or four students each, with team members separated geographically. Each team was given the assignment presented in Figure 2.

> ***Assignment:***
> *The assignment is to design a plastic product for the Design Forum Shop (http://www.designforum.fi/shop). The design team discusses products as well as brainstorms ideas to improve them. We'll come to hear the Design Forum representative's presentation about the concept of the shop. But we can already realize typical customers who are looking for something surprising and beautiful, something like a typical gift which is easy to carry with you in a suitcase or a small bag. A product's size at its largest is the size of two fists. In addition it's required that the product is built from three parts, which are connected to one another. The product is to be mass-producible, and production costs ought to be realistic. Printing or painting may be possible to use but may escalate costs.*
>
> ***Assignment hand-in form:***
> *The product is returned in a 1:1 ratio prototype, where the finishing is done as well as one A-1 sized presentation rendering (poster). Prototype parts can be produced using a 3-D printer at a later date, following further instructions, but fine-tuning is to be completed independently.*
>
> ***Exhibition:***
> *We will organize Design Forum Finland's exhibition, where the presentation rendering as well as the prototype will be available for audience and their feedback.*

Figure 2. The assignment

The course relied on a Moodle environment which provided tools for asynchronous communication. In addition, the design teams aimed to meet, virtually, every week. They were instructed to use *TeamSpeak* and *eBeam Interactive* during these virtual meetings. After the meeting, the contents of the discussion and decisions were saved into a weekly report and the sketches in the eBeam scrapbook were saved into the Moodle environment. It was also possible to use other communication channels if the progress of the design process was reported on the Moodle environment. The whole project from the first virtual meeting to the exhibition took about 20 weeks, but the most effective virtual collaboration occurred during the first 13 weeks. The model of LCD was introduced to the teacher, tutors and students at the beginning of the course.

Data analysis

The following results are based on a qualitative content analysis of the teacher's asynchronous communication, as recorded in the database of Moodle. The Moodle database was used as a window to observe teaching in VDS, but it should be noted that lectures with PowerPoint-presentations and virtual learning material [http://www.muovimuotoilu.fi] were excluded from the data. Firstly, the authors analysed communication links and teaching activities in VDS. The notes created by the teacher were segmented into statements representing separate meanings. Secondly, the codes were merged into three code families in order to examine teaching approaches. The analysis was conducted by ATLAS/ti computer program.

The macro unit of analysis was a "note." Following initial content analysis (Chi, 1997), the notes (n=225) created by the teacher were coded according to a scheme that emerged through interaction with the data.

- The first category consisted of the following starting-points of communication: (1) pre-work, (2) document, (3) question, and (4) activity.
- The second category, receiver of note, comprised the following aspects: (1) to all, (2) to team, and (3) to individual student.

Each note was considered to represent just one subcategory within these two categories. These subcategories were easily identified in the notes or in the communication threads.

Further, a second level of analysis was conducted. The micro unit of analysis was a "statement." Again, rollowing content analysis (Chi, 1997), the notes (*n*=225) were segmented into statements (*n*=559). We employed a theory and data-driven analysis similar to that in our previous studies (cf. Seitamaa-Hakkarainen, Lahti, & Hakkarainen, 2005). The analysis made use of the following categories: (1) design context, (2) design challenge, (3) new information, (4) design idea, (5) evaluating design, and (6) organising process. Each statement was considered to represent just one category in terms of its dominant content. For example, evaluating design consisted of the following aspects: (1) evaluating idea, (2) evaluating document, and (3) evaluating process. The categories and examples of the statements are described in Table 1.

Table 1
The classification schema

Teacher's statements	The model of LCD	Three teaching approaches
Requirements related to design task	Design context	Problem driven guidance
Constraints related to selected concept		
Sub-problems related to design	Design challenge	
Sub-problems related to usability		
Sub-problems related to manufacture		
Info related to plastic	New information	Solution driven guidance
Info related to modelling		
Ideas related to design	Design idea	
Ideas related to usability		
Ideas related to manufacture		
Evaluating idea	Evaluating design	
Evaluating document		
Evaluating process		
Use of VDS	Organizing process	Procedural driven guidance
Announcements		
Instructions related to reporting		
Division of labour		

Results

Communication links

In the Moodle environment, the discourse was structured by threads. To better understand the nature of communication, we identified both the aspects that promoted communication and the receivers of the notes. As noted, the entire database consisted of 225 notes posted by the industrial design teacher. From this database, the researchers identified four starting-points for communication. Teacher participation was the most active around documents (*n*=117, 52%) created by students. Around one quarter of the teacher's notes (*n*=62, 28%) were preparation for working in the design course. In addition, both the students' questions (*n*=25, 11%) and their activity (*n*=21, 9%) generated responses from the teacher.

Further analysis indicated that approximately 37% of the teacher's notes (*n*=84) were posted to all students; 52% (*n*=117) of the notes were written to the design team; while only 11% (*n*=24) of the notes were sent to an individual student. Figure 3 presents the distribution of the communication links. The results indicated that the communication was concentrated around the documents produced by the teams.

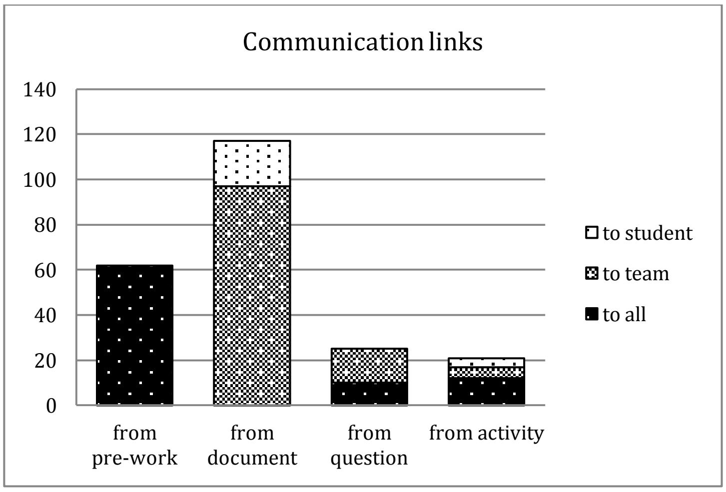

Figure 3. Distribution of communication in the VDS Moodle

Teacher-to-all communication

Communication between the teacher and the students was very structured. The teacher organised spaces for documents and discussion. There were six subject-areas in the Moodle: (1) a questionnaire for background information, (2) design tasks, (3) materials, (4) local discussions, (5) team discussions, and (6) links. The teacher posted notes and resources to all subject-areas.

The analysis indicated that the majority of the notes directed to whole class represented preparation for working in the design course (*n*=62, 74%). These notes contained course material, schedules, the use of VDS (e.g., Moodle, eBeam scrapbook, TeamSpeak) and announcements for all participants. For example, the teacher gave instructions for the use of the Moodle environment:

> *The assignment is returned to this discussion thread in a PDF format. Each group opens up a new discussion thread and begins with their document. The teacher comments on the document.*

Although the teacher gave detailed instructions for the use of discussion-areas in order to get systematic structure for communication, many messages and documents were saved incorrectly by the students. There was lack of clarity with several headings and communication threads. For this reason, it was difficult to follow some continuous episodes within the design teams. In addition to pre-work, the teacher responded to the students' activity and questions. The nature of the student's question determined whether the answer was addressed to all, to the team or to the one student. The following answer deals with the question of the design task:

> *I confirm Oscar's interpretation. The primary components of the product are plastic, and there needs to be as many as there are group mates. It can also have metal or even some simple electronic components. I don't however recommend designing a complex system like that of a cell phone.*

The analysis indicated that the teacher reacted to students' activity by sending clarifications and reminders through the Moodle environment. The following note represents clarification of the subtask, and was addressed to all students:

> *Wikipedia-article has been left unclear. The purpose is to write a short article about the information gathered during the process. The information is directly tied to your product or at least the information is found during the process. These articles will be linked on the Muovimuotoilu.fi website in order to benefit all those who are designing plastic products. The idea is that the source of the information is mentioned.*

Teacher-to-team communication

The analysis of the teacher-to-team communication indicated that it was centred on the design documents presented by the teams. The majority of the team-level notes (*n*=97, 83%) were linked to the documents. All teams had to post six documents into the Moodle environment: (1) selection of the product to be designed, (2) working plan, (3) background study, (4) concept plan, (5) article to Wikipedia, and (6) presentation rendering. Figure 4 shows Team 10's document regarding the selected product.

> ***Product:***
> *Ice cube-dispenser, with whose help we can separate ice cubes from their container without using our bare hands. This new one-handed mechanism is made from three parts: ice cube mold, hand part, where the mold is placed as well as a handle part, which is used to determine the amount of ice.*
>
> ***Environment:***
> *The target environment is primarily the home and kitchen.*
>
> ***Reasoning:***
> *We selected precisely this product, because it does not exist yet and we believe it to be needed. An ice cube dispenser combines ergonomics, aesthetics, ease of use as well as ease of repair. Its operation consists of a simple technical action and as such the product is suitable for practically everybody. The dispenser provides a working solution to the unpleasant effect of handling ice cubes; we avoid the freezing of fingers as well as we can better control the amount of ice cubes as well as avoid mistakenly dropping them onto the floor. The product is cost-effective to produce and all of its components can be made of plastic.*

Figure 4. Team 10's document describing their product selection

The teacher's feedback to Team 10 in regard to this document was:

> *Ice cube dispenser is a difficult assignment, but it fits the subject. It does contain moving parts, mechanics as well as ergonomics. The form of the document and its presentation were good.*

The analysis revealed that the teacher wrote 15 responses to teams' questions. For example, Team 10 presented a question concerning suitable materials for their design and got the following answer from the teacher:

> *What comes to mind is polythene-based foam plastic or EVA (Ethyl Vinyl Acetate), which has soft qualities as well."*

In addition, some notes (*n*=5) focused on a team's activity. The notes in relation to deadlines were typical in this category:

> *Apparently some of the groups did not notice that the deadline has passed. It was yesterday. We tried to make it clear and hoped that the return date would be taken seriously. The course's task is broad and if you don't get working on it quickly, it will end up unfinished by the deadline. It is essential to have time to do the products planning in detail.*

Teacher-to-student communication

Teacher-to-student communication, a minor component of all communication, represented only 11% (*n*=24) of all communication. This reveals that the teacher did not contact every single student (*n*=53) through Moodle. The teacher did, however, comment on all student-level documents (*n*=20) which were saved into Moodle. The students were guided to design individually a part of the team's plastic product, but not all students posted their detailed designs to the Moodle on time. Figure 5 presents a sketch produced by a student in Team 1 and the final construction of the toothbrush and rack.

Figure 5. Toothbrush and rack design (Team 1 student)

The teacher's feedback on the sketch in Figure 5 was:

> *The shape of the brush is beautiful. How well does it sit on your hand? The brush is manufactured using co-injection moulding. In order to keep the brush on the rack you need to extrude the hard part and after that add some softness. You need to be able to do both. So, what is the form of the hard part without the soft?*

There was no pre-work or questions in student level, but some notes (*n*=4) were classified as activity-based. The following excerpt shows how the teacher pushed the students to keep up with the schedule:

> *Thanks to those, who returned their part of the design according to the schedule. A large portion of students didn't. This is a critical phase because the final modelling shouldn't be started before the product's construction and functionality has been finalised. The feedback is meant to ensure that the product can be produced and assembled. Teacher and tutors will today go through the parts' designs and the feedback, so answer this message and tell me when we'll see your sketch.*

Teaching approaches

The Moodle database, as noted, contained 559 teacher's statements related to the model of LCD. The teacher's statements consisted of various categories of the design inquiry phases. The analysis indicated that 9% (*n*=52) of the statements defined the design context. In the design challenge notes (*n*=61, 11%), the teacher defined sub-problems which were to be solved. These two inquiry phases were defined to be the core of problem-driven guidance. The teacher developed the problem into three sub-problem areas: (1) design, (2) usability, and (3) materials and techniques for making the product.

The analysis indicated that some statements produced by the teacher represented new information (*n*=24, 4%); some represented design ideas (*n*=32, 6%); while the majority of the statements focused on evaluating design (*n*=248, 44%). These three inquiry phases were defined as the core of solution-driven guidance. New information was mainly related either to plastics or to modelling techniques. In accordance with sub-problems, design ideas were related to design, usability and manufacture. Through evaluation statements, the teacher assessed whether the design process was progressing in the desired direction, how the documents met the standards and how students' design ideas fulfilled the requirements.

The problem-driven and solution-driven statements focused on the design itself whereas the rest of the statements (*n*=142, 25%) focused on organising the design process. This phase was related to procedural-driven guidance. Procedural statements helped students to orient to the design process (e.g., the use of the VDS, announcements of lectures, instructions related to reporting, division of labour).

Figure 6 presents the distribution of the three identified teaching approaches. The teacher appeared to emphasise solution-driven guidance (*n*=304, 54%). The rest of the statements divided quite equally according to problem-driven guidance (*n*=113, 20%) and procedural-driven guidance (*n*=142, 25%).

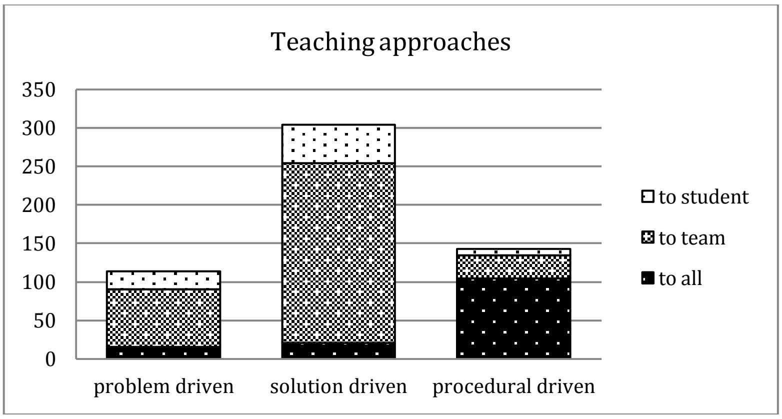

Figure 6. The distribution of the three teaching approaches

A second level analysis involved a question whether there were any differences between the problem-driven, solution-driven and procedural-driven guidance during the 20-week period of virtual designing. The analysis indicated that the teacher's participation increased after the documents were saved into Moodle environment (see Figure 7).

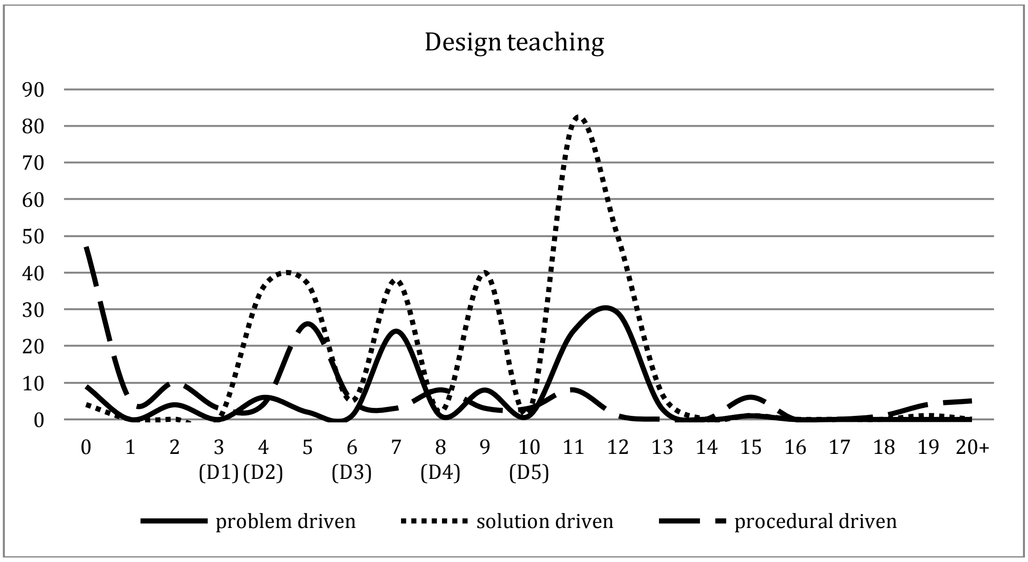

Figure 7. Design teaching during the 20-week period. Note: D1) selection of the product; D2) working plan; D3) background study; D4) concept plan; and D5) detailed plan for own part

Problem-driven guidance

The design task was a general and vague description of the desired product, giving only partial information about the customer, the purpose of the product and resources. Thus, it did not completely specify all the requirements, guidelines or desires for the product. The teacher facilitated students' understanding of the constraints and provided opportunities for them to extend and share their understanding. The main part of the problem-driven statements (66%; f=75) was addressed to the teams. As the previous analysis indicated, the communication was centred on the design documents presented by the teams. The most central document in problem-driven guidance was the third subtask. During this background study the students had to find out, for example, where the product would be used, who would be the particular user this product, how it would be used, what the specific requirements for the product are, and what the expected production volume would be.

Table 2

Three examples of statements belonging to problem-driven guidance

To all	To team	To student
The start point for the product is up to the design team. The product can be aimed at improving everyday life (can opener, key holder, cleaning tool, etc.) house appliance (clock, picture frame) or even an interesting accessory as long as during the assignment you mention the overall size, the amount of parts and material. Statement 3:101 - Code: [LCD context - Family: Problem driven]	*A series of 5000 seems on the small size. So the final product would be reasonably priced, we need to have the design- and production costs to spread over a large quantity. Usually this type of product are aimed at the global market where selling a million copies is possible.* 1:270 - Code: [LCD context - Family: Problem driven]	*This object could not be done with a simple mould, what kind of mould you have been thought about?* 2:163 - Code: [LCD challenge - Family: Problem driven]

The previous document held communication together and facilitated a problem-driven approach in both the students' and the teacher's point of view. In this approach, the teacher guided students in constructing a coherent design context by specifying requirements and constraints related to the design task or to the selected concept. In addition, the teacher guided the student teams away from problematic directions, permitting more manageable problems to arise. Table 2 shows three examples of the statements belonging to problem-driven guidance. The first one defines the design context, and it is addressed to all students; the middle one is a piece of feedback of the team's background study; and the last one is a design challenge based on the student's detailed design.

Solution-driven guidance

Problem-driven guidance focused on the question of what the problem is whereas solution-driven guidance pursued possible solutions for the problems. The analysis indicated that the teacher had three qualitatively different ways of supporting solution-driven guidance. The teacher appeared to emphasise evaluating designs instead of sharing new information or creating new design ideas. It should be noted, however, that lectures with PowerPoint presentations and virtual learning material were important sources of new information, but they were excluded from the data.

Solution-driven guidance was the most active at the team level. About 77% (f=234) of the solution-driven statements was addressed to the teams. There were three team-level documents that especially facilitated solution-driven guidance. The evaluation of the designs started after the teams returned the first document (i.e., selection of the product to be designed) into the Moodle environment. Later on, a team-level document (i.e., the concept plan) and a student-level document (i.e., detailed design of one's own part) served as devices for design communication. Table 3 shows examples of how these documents promoted both new design ideas and evaluation of the students' ideas. In addition, new information of plastics and modelling supported students' problem-solving process.

Further analysis indicated that the teacher appeared to evaluate students' documents and representational skills slightly more often than their real design ideas. Roughly 46% (f=114) of the evaluation statements related to the documents; for example: "Cross-sections are a great way to show the structural details, the dimensions well presented." Almost as many of the statements (42%; f=105) related to the design ideas, for example: "An accessory out of plastic is a difficult task. However, it fits as a Design Forum product." In addition, in some of the evaluation statements (12%; f=29) the teacher commented on whether the design process was progressing in the desired direction on time, for example: "If I understand correctly, then the product's prototype is still under discussion. So, it is not clear if it is an electronic device or not."
Table 3
Three examples of statements belonging to solution-driven guidance

To all	To team	To student
The innermost parts need to have a 0.2-0.4mm gap, so that the parts fit together. 1:383 - Code: [LCD info - Family: Solution driven]	*Could the same function work without moving parts, for example. By changing the shape of the base?* 1:339 - Code: [LCD idea - Family: Solution driven]	*The product's shape and structure looks to be different from the other groups?* 2:104 - Code: [LCD evaluating - Family: Solution driven]

Procedural-driven guidance

Procedural-driven guidance differed from the other ones. It was mainly addressed to the whole class (73%; f=104), not to the certain team or student. A typical statement to the whole class dealt with the use of the VDS, forthcoming virtual lectures or reporting requirements. At the team-level, the central document was a working plan which was intended to include a division of labour and responsibilities, a detailed working schedule and a plan for knowledge acquisition. With the help of this document, the teacher had the possibility of making recommendations to the teams. Table 4 presents examples of how the teacher organised the process at the three levels.

At the end of the course, each team succeeded in getting their prototype and presentation rendering ready for the exhibition. The final presentation in the University of Art and Design and the opening of the exhibition in Design Forum was the only situation where the students from the four different universities met each other face to face.

Table 4
Three examples of statements belonging to procedural-driven guidance

To all	To team	To student
In order to balance the poster print load we divide printing to three places: *Groups 1-6* *University of Art and Design* *Groups 7-12* *Lahti University of Applied Sciences* *Groups 13-17* *University of Lapland* 1:460 - Code: [LCD organizing - Family: Procedural driven]	*It would be great if you could already divide areas of responsibility, so that everyone could focus on their own area of expertise and nothing would be forgotten. Of course weekly we go into more detail on who does what.* 1:520 - Code: [LCD organizing - Family: Procedural driven]	*A final notice to those, who still haven't replied to the background multiple choice questions and free-form presentation. We're using this information for the breaking down into groups, so get your answers done and in by today.* 1:417 - Code: [LCD organizing - Family: Procedural driven]

Discussion and conclusion

Recent studies (Al-Doy & Evans, 2011; Chen & You, 2010; Rossi et al., 2012) of the design process have shown both the opportunities and the obstacles related to digital tools and virtual collaboration. The need to integrate digital design tools and real collaborative projects into design education has been emphasised. Yet the pedagogical aspects of virtual designing have not been studied intensively in the higher educational context. The present study offered a unique opportunity to observe a design course in which 17 teams of industrial design students solved a complex design task with entirely virtual means. The aim of the study was to analyse the teacher's work and orchestration of students' efforts in the VDS.

Traditionally teachers work as leaders and organisers of the collaborative design project. Virtual teaching requires a great deal of time to prepare course materials, to organise the learning setting and to communicate with the students. In the present case, the organisation of the whole project setting was very challenging because of the large numbers of participating design students that were geographically separated; for these, collaboration was conducted entirely by virtual means.

The results indicated that collaborative design was mediated by various design representations, such as plans, visualisations and 3D models. Mediating artefacts allowed the teacher and students to interact with one another through the object itself, as collaborating participants' activities were mediated and made visible through them. This is an essential feature of virtual designing where the participants do not meet face-to-face. According to Henderson (1999), visual representations work as boundary objects by holding communication together and facilitating distributed cognition in a design community. This point applies to the present case; the design teams' various documents contained the hints of knowledge that the teacher had to bring to the VDS. The results showed that the teacher's contributions were extensively built around the design documents. Problem-driven guidance was related to the background-study documents whereas solution-driven guidance was based on the concept plans and the detailed design documents. Procedural-driven guidance was mainly supported by the working plan documents. It should be emphasised, however, that these three teaching approaches occurred simultaneously during the design process. This is an important point when the designing process is seen in terms of the co-evolution of problem and solution spaces (see Dorst & Cross, 2001).

The virtual collaboration between design students has been studied more than virtual collaboration between a teacher and students. Sagun and Demirkan's (2009) study indicated that the critiques from both the instructors and the other students were more focused on the solution space than the problem space or representation. Likewise, in the present study, the teacher appeared to emphasise solution-driven guidance. Cardella, Atman and Adams (2006) have suggested that student designers be encouraged to develop their representation skills and to use more representational activities. In the present case, the qualitative content analysis of the teacher's notes revealed that the evaluation of the documents and students' representational skills played a central role; the students got much feedback about how their documents met the standards and their representations needed to improve. In some cases, the teacher recommended hand-drawn sketching and real muck-ups in parallel with computer-aided design and modelling. Despite rapidly developing design technology, material representations, such as hand-drawn sketches and real prototypes continue to have a place in exploration and idea generation within the design process.

To conclude, the teacher is needed to structure and orchestrate the collaborative efforts and provide guidance for design learning. In the present educational setting, the teacher was able to follow only the teams' documents, not the entire design process in progress. Thus, the students had to take responsibility for their learning—determine what it is that they do not understand and how to proceed with the task. This required a shift from teacher-centred to student-centred learning and from individual learning to group learning. Nonetheless, the teacher's guidance was crucial in expanding the progressive, design inquiry. According to our study, the model of Learning by Collaborative Designing can be used to provide guidelines for teaching. The LCD model was originally developed (Seitamaa-Hakkarainen, Lahti, & Hakkarainen, 2005) to serve various levels of design and technology education (for primary, secondary, and higher education) in order to communicate computer supported collaborative designing with new teachers and students.

Accordingly, an essential aspect of LCD is to engage collaboratively in improving the shared design ideas or pursuing some other mediating design objects (e.g., concrete prototypes, products) that emerge during the process. The teacher can use the model to create a design project's infrastructure by considering the role of design documents and models of interaction that facilitate collaborative designing. Besides thinking of prepared structures such as design tasks and tools, the teacher could develop his or her personal guidance during the design process. It takes a special skill to generate problem-driven not just solution-driven guidance. The teacher and students together can use the LCD model for reflection on the design process; they can reflect and evaluate how collaborative design processes have proceeded, how problem-driven and solution-driven strategies are employed and how the process has been organised.

The format of the virtual studio teaching permits participants to employ a variety of interactions and methods. However, it is not easy to implement sophisticated pedagogical ideas in technology-mediated collaboration (Kali, Goodyear, & Markauskaite, 2011). The design teachers have to find a balance between prepared structures and improvisational activities in VDSs (cf. Sawyer, 2011). It is essential that VDS *not* be used merely for transmitting knowledge to students, but also for facilitating students' engagement in collaborative designing.

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