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TANGIBLE 3D MODELLING: BRIDGING THE GAP BETWEEN PHYSICALITY AND VIRTUALITY

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ABSTRACT
This paper presents an experimental approach to teaching 3D modelling techniques in an Industrial Design programme. The approach includes the use of tangible free form models as tools for improving the overall learning. The paper is based on lecturer and student experiences obtained through facilitated discussions during the course as well as through a survey distributed to the participating students. The analysis of the experiences shows a mixed picture consisting of both benefits and limits to the experimental technique. A discussion about the applicability of the technique and about the needed adjustments concludes the paper.

Keywords: 3D modelling, SolidWorks, tangible free form models, physical artefacts, inductive learning, physical 3D modelling

1 INTRODUCTION

3D modelling is often considered to be one of the important technical skills learned in design educations, and to many graduates the ability to demonstrate superior modelling skills can be critical when applying for a job in the industry. Consequently, a course in 3D modelling with one of the industry software standards has always been part of the formal curriculum for the Industrial Design programme at Aalborg University. During the years a lot of effort has been put into improving the course and meeting the students' needs. The latest experimental initiative on the 3D modelling course had the purpose of addressing some of the students' reluctant attitude towards modelling complex shapes by increasingly stimulating their modelling-strategic considerations with the use of tangible free form models. This experiment should be seen as an attempt to bridge the gap between students´ understanding of the software features, and the physical world as described in Romiszowski [1] where a differentiation between "reproductive" and "productive skills" is established. Where traditional software courses often seek to teach by a deductive approach, the approach of the given course have been on teaching by an inductive-deductive approach, as described in Felder & Silverman [2], thus creating an formal-experimental learning environment.
This paper presents the learning from the experiment and discusses how untraditional media or artefacts as modelling wax can assist the learning in different ways. Whereas the free form models contributed to a better understanding of the sometimes rather difficult modelling task by bridging the gap between the desired result and the actual virtual model, the models also supplemented the course in other ways. Among other things, the tangible free form models helped emphasise the importance of the discussions about modelling techniques and approaches as well as about the beauty in shapes and curvatures throughout the course and furthermore made the evaluation of the students' work more interesting and joyful. However, during the experiment, a number of weaknesses in the technique were also identified. These are also taken into account in this paper. Besides the already mentioned discussions, the present paper also include examples of the students' work and establish some guidelines for an approach to using tangible free form models as facilitation for learning virtual 3D modelling.
A number of existing research projects have earlier been focusing on the interrelationship between tangible, non-digital media such as paper or physical models and intangible, digital media such as CAD models as a critical part of the design process. This project therefore partly builds on the contributions of Song et al. [3], which describes an efficient method for alternating between physical and non-physical models, and Brereton and McGarry [4], who have studied how objects support

engineering design thinking. From a pedagogical perspective, the present experiment draws on insights about how to facilitate *individual learning* presented at E&PDE 2011 by Pütz & Intveen [5]
Also Hiroshi Ishii [6] investigates the interrelations and possibilities in combining a graphical information environment and a tangible information environment, thus creating an enhanced understanding of the underlying functions and concept.
The rest of the paper is composed as follows: Section 2 presents the fundamental research setup and the specific methods used. The third section contains the results of the research efforts and consists of visual material in combination with both quantitative and qualitative data obtained during the course. The results are analysed in section 4, and a discussion about the technique and future adjustments is finally presented in section 5.

2 RESEARCH SETUP AND METHOD

This section presents the research setup and the experimental method developed for the purpose of the 3D modelling course. It also includes a brief overview of the course progression with implementation of assisting free form models.

2.1 Course overview

The course in 3D modelling with SolidWorks is a well-established part of the bachelor programme for the Industrial Design education at Aalborg University. Traditionally, the course has been positioned on the 6th semester, but due to a recent revision of the Industrial Design curriculum, the students attending the particular course come from both 4th and 6th bachelor semester. Organised in five lectures of each a half day, the course programme is composed as described in Figure 1 below.

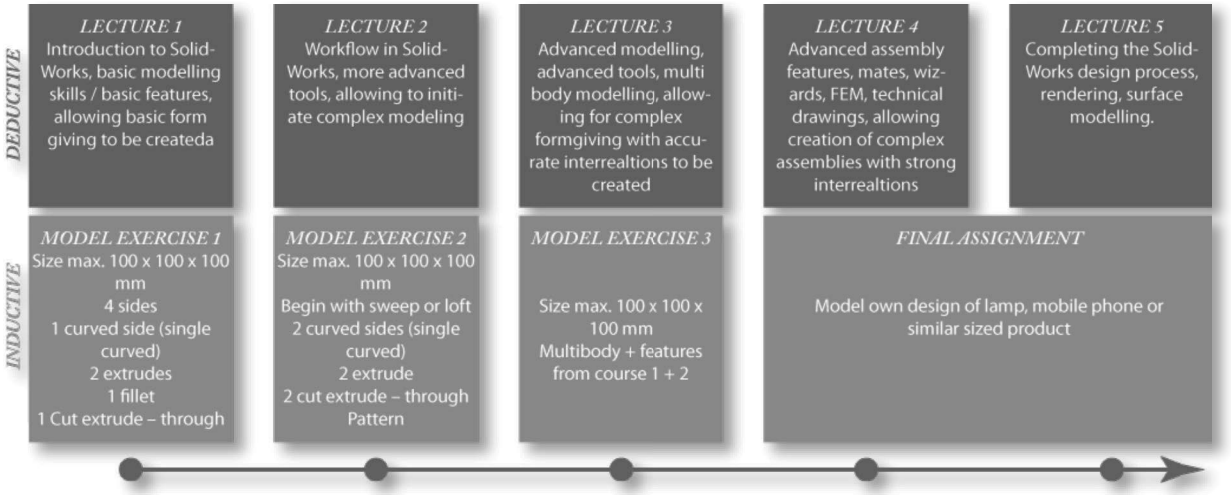

Figure 1. The overall course programme showing both the deductive and the inductive learning

2.2 The experimental assisted modelling technique

During the course, the students were asked to create increasingly more complex tangible free form models in modelling wax. The instructions given to the students were a series of requirements for each model as exemplified in the list below:

- Size: max. 100 x 100 x 100 mm
- 4 sides
- 1 curved side (single curved)
- 2 extrudes
- 1 fillet
- 1 Cut extrude - through

This set of instructions related to the specific learning given to the students in the lectures, so the model both related to 3D software specific instructions and to abstract information, subject to individual interpretation.
After building the models, the students were asked to switch models and build the model of the student next to them in SolidWorks, thereby eliminating the possibility to create an easy task for one self. Before beginning the tangible modelling, the students had to make a strategy for the entire modelling

process. This strategy should focus on creating a tangible model with strong relations to the SolidWorks features taught in the corresponding course, thereby learning, in tangible form, the SolidWorks processes, as seen in figure 1. This is not always the easiest way, but could be a complex division of objects in order to maintain parametric overview.
The combination of tangible free form modelling and strategic considerations about how to approach the modelling process in the software were the experimental addition to the course, creating both abstract as well as strategic considerations for each of the students.
As a final assignment in the course, the students were asked to design a small product using tangible free form as part of the design process. The detailed and physical product concept created the basis for modelling the product in SolidWorks. The purpose of this assignment was to free the students from the strictly specified exercises presented to them in the earlier lectures during the course and thereby allow them to establish a certain independency, ownership and control in regards to their modelling competencies.

2.3 Research methods

The experiences with this experimental tangible free form technique were captured by a number of different ways. The primary way of identifying the value of the method was through an on-going discussion with the student taking part in the experiment. The instructors of the course facilitated this discussion on the class in each lecture. Both tangible free form models and virtual 3D models were documented through photographs and screen dumps and compared to each other in order to get an overall impression of the similarities. Finally, a web survey consisting of both quantitative multiple-choice questions and open questions with written answers was distributed to the students. This survey had the purpose of engaging *all* students in the reflection process about the experimental method.
The gathered data was collected and sorted by the instructors of the course and will be briefly presented and analysed in the next sections.

3 RESULTS

Discussions with the participating students have provided valuable feedback on the technique throughout the course. In general, the students have given the technique a good reception, and it has been easy to spot the enjoyment of the students working with the tangible free form models. Figure 2 below may very well reveal the inherent playfulness, which is triggered by the modelling wax.

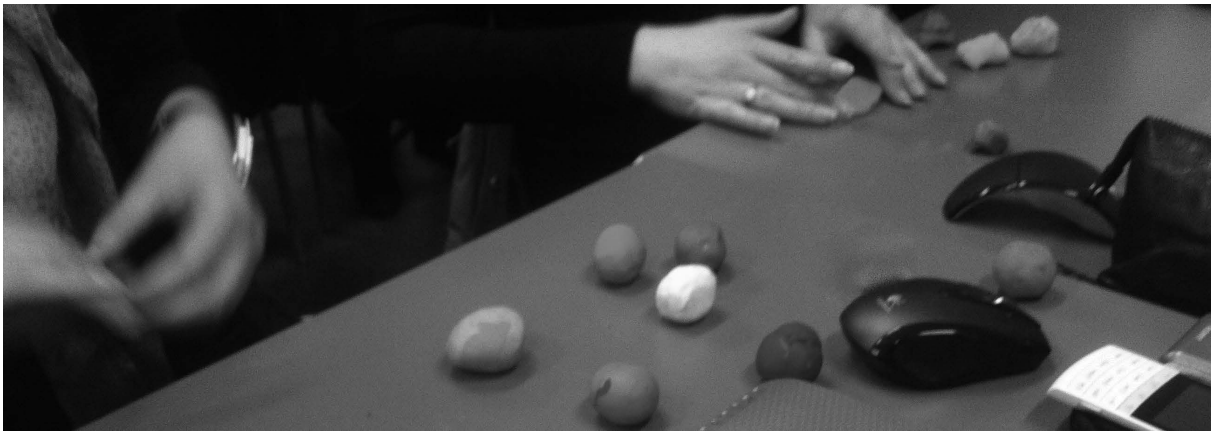

Figure 2. Students building tangible free form models in modelling wax

3.1 Corresponding Models

The models made in modelling wax are often quick and rough 3-dimensional sketches that serve as tools for engaging creativity. Figure 3 below shows an example of a simple model transferred from one media to another. The corresponding models ignite discussions about topics like their mutual comparability or their communicative qualities as conceptual prototypes.

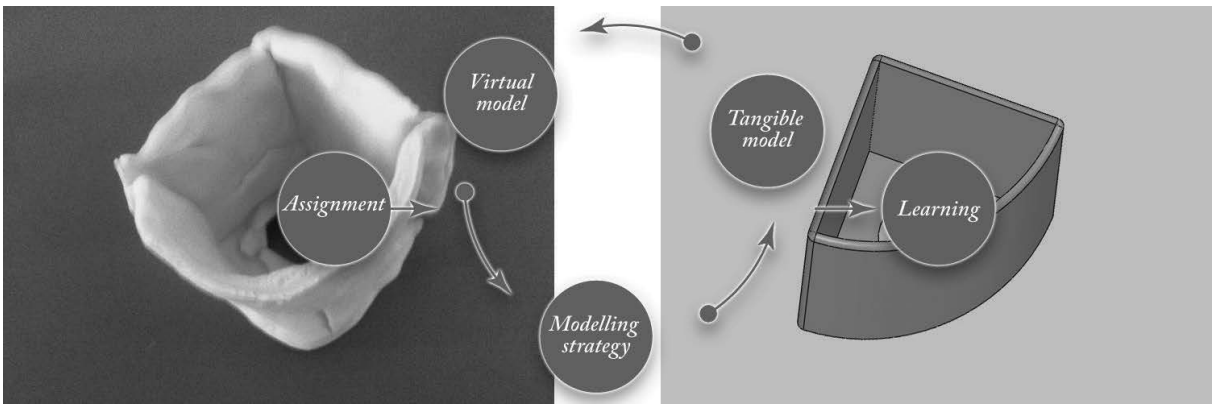

Figure 3. Example of transfer from simple clay model to virtual model in 3D environment

3.2 Results of the Survey

In Figure 4 and Figure 5 below are some of the most significant findings of the survey presented. These findings reflect the tangible free form models' influence on practicing SolidWorks as well as the students' overall impression of using clay as part of the SolidWorks course.

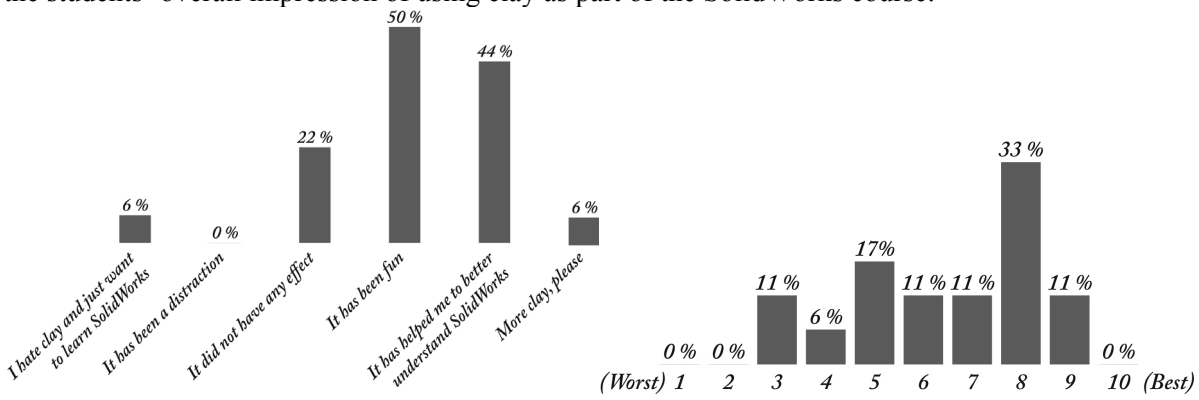

Figure 4. Tangible free form models' influence on the practicing SolidWorks.
Figure 5. Overall impression of using tangible free form models in SolidWorks training

The survey also included questions for written answers, and some representative answers are brought forward in Table 1 below.

Table 1. Quotes about benefits and downsides when using tangible free form models in the SolidWorks modelling course

Benefits of using tangible free form **models**	**Downsides of using** tangible free form **models**
"You get a better idea about how to build the SolidWorks model."	"It could be modelling wax, just as it could be LEGO bricks or something different."
"It's nice to have something tangible to look at when modelling in the program."	"The modelling wax give some limitations in respect to modelling. Precision is difficult."
"It has been a positive experience to use both head and hands in different ways. It challenges and awakens the creativity."	"You might use more time than necessary on building the free form models."

4 ANALYSIS

The results presented in the previous chapter revolves around the students' experiences of using modelling wax as a media of understanding how tangible and physical qualities of products are best transformed into a virtual and spatial representations in a 3D environment.

As it is seen in Figure 4, 50% of the students found the use of tangible free form to be fun and 44% of the students answered that they found the use of tangible free form models to improve their learning of SolidWorks. However, a relatively large part (22%) of the students did not see any effect in using tangible free form models.

One reason for including tangible free form models in the course programme has been to evoke the students' desire to experiment and loose the initial reluctance towards the software, which is new to them. From the survey conducted among the students, and through the continuous discussions throughout the course, it is clear that the focus on building tangible free form models removes some of this hesitation towards experimenting with the software.

Several students have raised the question of whether the tangible free form modelling had to be done by the use of modelling wax. They argue that lack of precision and disproportionate use of time speak against using this as modelling tool, but still they find the use of physical models a benefit. It is the impression of the instructors that modelling wax to a large extend can be replaced with other physical items or modelling tools, but seen in a perspective including the full course, modelling wax is a preferred tool for the final assignment in which the students have to design and build a small product themselves.

When looking at Figure 5, two thirds of the students are positive or tending towards positive when it comes to their overall impression of using the clay in the SolidWorks course. This also means that one third is negative or tending towards negative in their overall impression. Even though these statistics indicate that clay models assisting a 3D modelling course results in a mainly positive outcome, one third still is a relatively big part of the students not being happy with the technique.

5 DISCUSSION

So far, this paper has presented a technique for learning SolidWorks modelling to students in the bachelor programme in Industrial Design. The technique combines tangible free form modelling in modelling wax with the actual 3D modelling activities in SolidWorks. Through a series of on-going discussions with the students as well as through a survey about the student's experiences with the technique, it has come clear that the technique has certain qualities in regards to the learning of SolidWorks modelling. However, a rather large group of students did not find the technique beneficial to their personal learning.

From these results, the right question to ask has to be whether the tangible free form technique has earned its right to be part of the permanent SolidWorks course programme? On the one hand, it is clear that the technique supports a certain individual learning as it allows the individual student to explore the modelling opportunities on her own hand. It thereby has the potential of establishing the needed freedom for both *quick starters* and *slow learners* as well as *thorough learners* [5], which is often a challenge in many educational settings – and in particular in courses concerning software training. On the other hand, the tangible free form modelling tasks risk distorting the actual focus and purpose of the course: Learning *virtual* 3D modelling. The data collected in this experiment, both quantitative and qualitative, are insufficient to clearly answer this question, and further refinement on the experiment has to be a quality test of the students learning output, e.g. by collecting sufficient data for a quantitative analysis, or perhaps sub dividing the students into smaller groups, with control groups, in order to test the actual benefit of the course.

Whereas the instructors of the course see many positive effects in the experiment, they also see some downsides in the present setup. Creating tangible models as a starting point pushes the students further in regards to what they would otherwise try to accomplish in virtual models. In other words, the modelling wax is rather strengthening than limiting the students' perception of what they might obtain with SolidWorks as it allows the individual student to "compete" with oneself. This is a clearly positive effect. On the other hand the *free-form* models could have a tendency to go beyond the defined task and such bindings as a *single curved surface* was often translated into physical models that the students were unable to model in virtual space, simply because of the lack of training and general overview of the possibilities in the 3D software.

From a pedagogical perspective, slowing down the general pace of the learning process by forcing the students to implement free form models, was generally a good thing, even though some students though differently. The delay helped maintain an actual design process instead of students jumping into SolidWorks modelling without important considerations about proportions, visual expression and basic construction principles. The creation of an inductive / deductive mixed learning environment gave the students a real chance to learn by experience, and thereby a possibility to implement the learned skills into later design processes. The overall course setup where both a physical and a virtual part were presented allowed some of students to bridge the gap between the physical and the virtual universe by themselves, attaining a *reflection in action*, as described by Agyris and Schön [7]. The goal of the course could be to establish a *refrection on action,* also described by Agyris and Schön [7], thereby enabling the students to go back and redefining their overall approach to the 3D modelling design problem.
An important learning in the course programme is to make the students aware of how 3D modelling in SolidWorks can assist their overall design workflow from the very first conceptual ideas to the final production ready digital 3D models.
Lastly, the creation of physical models strengthens the modelling-strategic considerations, which are vital when building parametric 3D models, and thereby serves as an important mean for learning.
As mentioned did the instructors also experience some downsides to the technique, which have to be addressed if the technique is to be used in the course again. Students mentioned that building the tangible models took too long time due to the complexity in the instructions. The instruction set included rather many different modelling features as their purpose was to ensure that the students got to work with all the possible modelling features in the software. However, this may be done in other and simpler ways by allowing more freedom into the tangible model making. Another comment from the students was about the choice of modelling wax. They argued that other media such as LEGO or similar could be just as good. As mentioned earlier did the instructors find the use of modelling wax rather superior in some respects, but would also consider combining the modelling wax with other tools in a new and adjusted version of the course programme.
As a closing remark on the course setup with tangible free form models as part of the SolidWorks programme, the instructors found the experiment to be a general success. Clearly, there have been some great benefits that would make it obvious to use in the courses to come, but it is also evident that it has to be considered as an initial attempt that needs the adjustments mentioned above in order to reach an accepted level of maturity in order to become part of the curriculum.

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