FLUX: Design Education in a Changing World

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Teaching production technology – doing more with less

Abstract

"How does my design work?" and "How can it be produced?" are the two key technological questions that the industrial design engineer must be able to answer. Looking at the second question, we see that there is still a lot to be gained: 60% of all new products do not enter production as scheduled, with 25% of these products requiring major redesign. In part, this problem can be traced back to industrial design education. Here, production processes are traditionally presented from a phenomenological perspective only, failing to communicate their inherent limitations and possibilities. Also, traditional education could stimulate students' imagination more when it comes to production and needs to debunk the myth that the field is "something for experts only". Education on production technology is clearly in need of a new approach.

The faculty of Industrial Design Engineering of the TU Delft is currently introducing a revised bachelor program, featuring a new approach towards the treatment of production technology. The three key elements of this approach are (1) integration of design and technology, (2) through physical modelling, letting students understand the trade-offs between design freedom, product quality and price; and (3) in cooperation with industry, allowing students to explore unusual but promising new production methods. In accordance with current instructional insights, this approach is also designed to activate the students as much as possible, e.g. by having them participate in workshops and design activities. To make all this feasible, the range of production processes being covered is greatly reduced; hence the designation "doing more with less".

The bachelor revision is currently underway and at this point in time, it is therefore impossible to give hard results on its success. Still, on the basis of small-scale trials, it can be concluded that the new approach offers excellent potential. Not only do the students learn better to deal with production-related design questions; they also learn to base design decisions in general on the results of physical modelling, making design practice better-supported and less ad hoc.

Design education, and design in general, has a lot to gain from a more knowledge-driven approach, provided that this does not diminish creativity and originality. Shorter design processes and better products are merely the most visible benefits: making the field more professional will also be a consequence, as will its improved academic standing. The authors view the new approach as sketched above as a step towards realizing these benefits.

Key words: *Design education, production technology, understanding through modelling.*

Introduction

From a technological perspective, there are essentially two questions that need to be answered during the development of any product. The first question is: does the product deliver the required functionality, in other words, does it work? The second question concerns the realization: can the product be produced at a (perceived) cost that does not exceed the market value of its (perceived) functionality? This paper deals with this second question, in particular how industrial design engineering (IDE for short) students can learn to address the realization issue.

The basic problem this paper focuses on, is the observation that no less than 60% of all product development projects, relating to new products as well as to redesign, still encounters delays in the scheduled production; 25% of these projects (or 15% of the total) even needs major redesign (Deugd, 2004: 8). In an age where product lifecycles get shorter and rapid market introduction of new products therefore becomes more and more crucial to economic success, this is a disappointing finding. It is all the more unsettling if one considers that comprehensive methodologies to prevent such problems, such as DFMA (short for 'design for manufacture and assembly'), have been around for 30 years (Boothroyd, Dewhurst and Knight, 2002: 1-41). Also, professional product development manuals generally address the realization issue in considerable depth. For instance, (Andreasen and Hein, 2000: 27) argue that specific and early attention to production-related issues can prevent undue delays and extra cost. The authors would like to suggest that such attention can in fact unlock new technological potential, creating solutions and value instead of causing problems and cost. For an example, see (Tempelman, 2001: 5).

Despite this consensus, we still see the production problems mentioned above. The authors conjecture that improving the way in which production technology is taught in universities can help to provide a solution. The current teaching approach is not without merit, but presents the subject in a phenomenological way, i.e. by listing facts and properties, without consistent reference to the underlying physics (e.g. materials engineering knowledge, thermodynamics). Also, many IDE students currently perceive the subject as somewhat dull and unchallenging, as “just another course to pass”. In fact, some of them report that they do not consider materials selection, and by extension, production process choice, to be real design work (Kesteren, Kandachar and Stappers, 2006: 1-4; Kesteren, 2007). During IDE education, production technology is too often seen as a field for experts only.

This paper presents an alternative teaching approach. It is aimed primarily at university teachers in the field of IDE education, but the findings can be extended to mechanical engineering programmes and similar domains as well. The paper first provides several relevant instructional perspectives, then moves on to the educational concept adopted for the new TU Delft IDE bachelor program. The new course, based on the alternative approach is then described, after which the paper ends with some tentative conclusions.

Some instructional perspectives on IDE education

The intended learning results of industrial design (IDE) engineering education imply that the educational program should address knowledge, insights, skills and attitude, instead of only knowledge. The competence in production technology we are aiming at also implies that students understand the context of the professional practice and are able to link this context with the competences that are needed for a designer in that context. The learning and instruction processes that are needed to realize this aim can only be based on a range of student activities (Brew, 2006; Bulte and Pilot, 2005: 11-16). They should understand the kind of problems that designers face when planning the production of a design, be motivated to know more of problems and solutions, and understand how the production principles determine the possibilities and limitations of production methods and equipment.

Such an approach requires multiple learning and teaching formats, related multiple activities of the teachers, project work and involvement of professionals from industry partners. This can be seen as the ‘instructional principles’ on which the entire new bachelor program is designed. Ideally, the plenary lectures fulfil the function of motivation and broad orientation on the principles and key concepts. In the guided instruction students will make these principles and concepts operational in specific activities in interaction with the teacher and other students. In the assignments they again will feel the need-to-know-more when applying principles and concepts in larger, more complex and more authentic tasks in teams. Specific attention is paid to the authenticity of the tasks, related to the professional practice in order to stimulate a whole-tasks approach and to motivate the students for this field of their future design work. In this approach the focus of student activity is based on authentic practices as the source for assignments (Bulte *et al*, 2006: 1078-1084). This also implies that in the assessment the results of student activity should be meaningful for the student and for professional practice, so representatives of the industrial partners will be involved in the assessment.

The relation between the professional practice (the context) and the body of knowledge they should become competent in, is based on two principles: (1) explicitly the relations between the production principles, the production methods and the production equipment should be presented, and (2) activities are needed in which students reflect on the content and meaningfulness of their experience in the assignments. In trying to educate students on a wide range of topics, it is necessary to help them structure those topics well and to let them use previously-obtained knowledge to gain new insights. In the new second-year course, production processes are first structured and then explained using first-year materials engineering knowledge. The sequence of learning and teaching activities requires careful attention because of the level of abstraction. Starting from a low level of abstraction with concrete products and processes they know of or can intuitively understand from demonstrations and video, the more abstract principles are introduced and made operational in the assignments (Van Hiele, 1986: 49-57). Iteration between levels of abstraction for the different topics in this way can then be based on an understanding of how the principles are related to each other. The use of well-selected examples to show the paradigm on which the relations for these topics are based and is used in the assignments by the students is essential (Freudenthal, 1978: 202). Reflecting on results of their assignments (Schon, 1987) is an integral part of the students' activities in order to enhance their understanding and attitude for the relations and the way of production as industrial design engineers.

Educational concept of the new TU Delft IDE bachelor program, Sept. '07 and on

This section summarizes the new educational concept adopted by the Faculty of Industrial Design Engineering (IDE) for the bachelor program. It is adopted and translated from (Bos, Morel, Roozenburg, Sprangers and Versteeg, 2006). In this concept there are fewer courses than before, but the courses are bigger and more multi-disciplinary in nature; also, there is substantially more choice for the student than before. Please refer to the full source for more details on the principal assumptions underlying the concept and its characteristics, as well as to information on its implementation.

The IDE bachelor program is founded on competencies. Knowledge, insights, skills, and attitude are addressed not so much as separate areas, but in conjunction with, and in the context of, professional practice. Therefore, as much as possible, the program provides instruction in the form of tasks and projects related to professional product development. This is done using a variety of teaching formats, which vary dramatically in the student number they address: plenary lectures (up to 300 students), group instructions (up to 30 students), project work (four to six students), practical assignments (duos) and self-study (usually alone). Also, over 50% of the program consists of active formats against around 30% for its predecessor, translating into roughly 25% higher staff deployment per student but also into a expected higher first-time pass rate and increased effectivity, and ultimately in increased efficiency.

Discipline-related knowledge and skills are linked primarily to product design projects, because the related learning objectives are achieved best when they are directly needed by the students for executing the assignments. Testing the knowledge and skills is also timed closely to the completion of the projects, with additional formative (i.e. informative) evaluation through peer feedback and one-to-one contact between teacher and student. In these projects, the coach is supported by specific staff experts in preparation and coaching. More specialist knowledge and skills than before are called on in assisting the projects. This assistance is expected to contribute to higher-quality student results.

To assure the freedom of the student in personal development, the IDE bachelor program offers a lot of personal choice. In fact, the entire third year is filled with elective program elements: a one-semester minor (to be taken at a different program than IDE), two elective courses of 210 study hours each and a final ten-week individual design project. (By comparison: the previous program had no options at all.) Enabling personal choice is in line with stimulating students to take responsibility for their own education. Also, it is known to increase student motivation (Innes, 2004).

In order to clarify students' competence development, more use is made of formative evaluation than before, alongside with summative (i.e. selective) evaluation. This used to be done on an incidental basis only, but is now part of all courses. From 2008 on, students will also be monitored across course boundaries in the product development projects; later even across projects and courses. In the projects themselves, students are always assessed by their project coach and by an independent assessor. An important new aspect of evaluation is that the students themselves take on some of the burden of proof to demonstrate that they have the required competencies.

The IDE Bachelor's Coordinator supervises all crucial matters of the program, such as the relationship between individual and group performance, group composition, the reporting method, regulations on determining final course marks, the number of tests and examination method for a course and the number of company contacts. Also, s/he bears final responsibility for the integration between the courses and the product design projects.

Teaching production technology: the new course

In the new TU Delft IDE Bachelor program, production technology is already introduced to the students during two of the total of six first-year courses. In these courses however, the subject receives only limited attention and it is in fact presented in a way that stimulates asking questions rather than giving answers. The same holds for the two first-year product design projects. Thus, at the end of the first year the students are intended to have their ‘need to know’ firmly established, setting the stage for the second-year course ‘Industrial Production’. This is a ten-week course, scheduled to take the average student a total of 210 hours to complete (i.e. 50% of their time during this period). It aims (a) to give in-depth knowledge of the most relevant production processes, (b) to show how information on new or unusual production processes can be obtained and structured; and (c) to indicate how the right production process choices can be made. It is described in detail below. Production receives additional attention in one subsequent second-year course as well as in the fourth product design project, and should of course be duly addressed by the student in the final bachelor design project.

During the first five weeks of the new course, the students receive two plenary lectures and two guided instruction sessions (with up to 30 students per teacher) per week. One or two different production processes are covered per week. The lectures feature the liberal use of video material as well as actual product samples. In this thematic set-up, a clear structure is used, in which production is considered on three levels of abstraction: (1) the production principle, (2) the production method; and (3) the production equipment. As an example, Figure 1 below shows how these levels can be used to structure the variety of metals casting processes. The implicit message is that one can understand a variety of methods by what they all have in common: the production principle. At the same time, the use of concrete examples and videos prevents this principle from becoming merely a verbal abstraction.

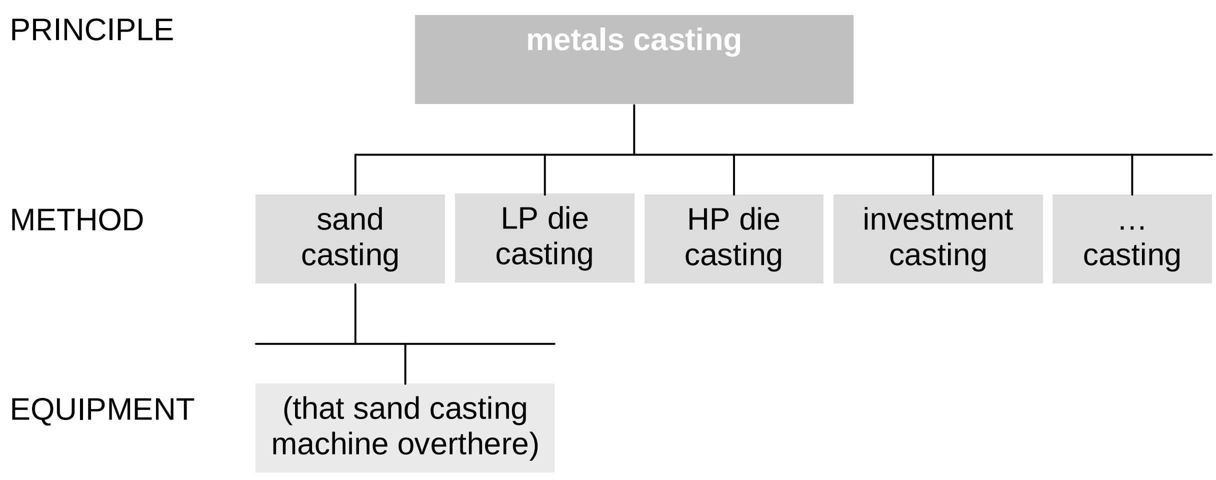

Figure 1: abstraction levels in metal casting processes

Especially during the guided instruction sessions, students learn to model the production process at hand using elementary physics and first-year materials engineering knowledge, i.e. they learn to extend what they already know to a new field. Since the sessions are limited in time (two hours each, with two additional hours of self-study), special care has been taken to ensure that no time is wasted on trivial issues; also, students are strongly stimulated to be active and be prepared. For instance, in preparing for the session on metal casting, they need to work through a specially-compiled ten-page reader containing text, tables, graphs and questions. Furthermore, they are asked to bring a suitable product sample with them (either real or as a picture).

The modelling itself is very basic but efficient. It starts at the level of the production principle. Returning to the example of metal casting, this is the content: the students first learn to couple casting speed to metal flow speed, before moving on to calculating how much heat a given casting must lose during solidification and how its volume-to-surface ratio (= design variable!) determines the cooling time (i.e. Chvorinov's rule). The modelling ends with estimations of how thickness variations in products can lead to thermal cracking (in industry practice, this of course requires computer simulations, which are in fact shown in the plenary lectures, along with samples from the faculty part collection). To round up the session, the students then jointly *draw up design guidelines on the basis of the modelling*. In doing so, they move down one abstraction level, and discover e.g. that one should not generalize guidelines too easily.

These exercises aim to give a well-founded insight in the inevitable trade-offs between function-, cost- and quality-related aspects of production processes. For instance, moving on to plastics processing, the students discover that it is largely due to the much larger pressures that injection moulding offers more freedom of form than thermoforming – but precisely because of those larger pressures, the investment is much higher also. This is the kind of insight that is required to pass the course; the actual design for production is a part of the subsequent product design project.

During the second half of the course, the students still receive lectures, but the instruction sessions are replaced by a 42-hour group assignment. In this assignment, students visit an industrial production company and document what they see there, using the structure they learned before. Here design and technology are to be integrated: "how does it work?" as well as "what can I do with it?" need to be answered. The assignment ends with a presentation of their findings to their peers. To add gravity to this event, the company is present here as well, and the outcome is also exhibited in the faculty's part collection. To prevent copying, a new set of processes is covered this way each year.

The important subject of production process choice is used as the start of the entire course as well as its ending. It is presented not as a single event (which it is not), but rather as the gradual definition of the various options through the three abstraction levels mentioned above. Concept development then requires a choice on production principle (e.g. metal casting or plastics injection moulding), embodiment design one on production method (e.g. sand casting or investment casting), detailed design on the production equipment (e.g. investment casting with machine X or Y). With this set-up, the authors aim to help IDE students make the right choices during their design projects, as well as to stress the relevance of such choices to the field of industrial design itself.

All in all, the new course addresses fewer different processes than before, but in greater depth: hence the designation "doing more with less". Students who desire more information, for instance when doing their design projects, are referred to the Cambridge Engineering Selector (Ashby and Johnson, 2007: 89-99), which is available and accessible at the faculty, and to selected literature.

Conclusions

At the time of writing (August 2007), the new TU Delft IDE bachelor program is still in preparation, including the new course 'Industrial Production'. Starting in September, the program will be introduced, with the new course starting in November this year. At this point in time, it is therefore impossible to give results on its success. During the development, however, the authors conducted some small-scale trials with the new approach, ranging from one-to-one interviews with students to instruction sessions with small groups that were similar to the intended guided instructions.

The outcome of these trials was as follows. To their surprise, the IDE students discovered that many production-related design issues can in fact be understood in terms of elementary material science (for instance, learning that the minimum bending radius of a metal sheet can be expressed as a function of the metal's uniaxial failure strain). They also enjoyed the fact that through understanding one production principle, they can understand a range of different production methods. Finally, they got an impression of how engineering science can be used to support design choices properly, making design practice more rigorous and less ad hoc. Unfortunately, we have not yet had the opportunity to verify these results through student exams or through analysis of student design projects, but the outcome is sufficiently positive to go ahead with the new course.

Once it is running, the course will be monitored to see if it achieves the targets that have been set for it and if the assumptions behind it are true. Among other factors, student motivation and reaction, as well as first-time pass rates and other efficiency indicators will be tracked. The results will be used to fine-tune the course and will of course also be made available for peer review and feedback.

The authors expect that design education (and by extension, design practice) has a lot to gain from the understanding through modelling described in this paper. Although it will be difficult to verify this (in fact, impossible in the short term), it will contribute to reducing the problem stated in the introduction: less production delays for new product development projects. Also, the students are expected to find the new course more motivating than its predecessor and to learn that production is in fact *not* for specialists only. To what extent the field can be presented as a source of solutions rather than problems remains to be seen: after all, this is dependent on creativity and originality as well as on engineering knowledge.

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Erik Tempelman holds a position as assistant professor at the TU Delft, faculty of Industrial Design Engineering, department of Design Engineering. Prior to this position he worked for the automotive industry for five years and as a consultant at the Dutch Institute for Applied Sciences (TNO) for two years. Before that time, Erik obtained a Ph.D. at TU Delft on sustainable transport and advanced materials. His main field of interest is production technology and its implications for design, in particular Medisign.

Educational responsibilities

Currently, Erik's main educational responsibility is to develop a new bachelor level course on industrial production, as part of the all-new bachelor programme that will be rolled out in September 2007. In the master programme, he is the course coordinator of Project Advanced Products and acts as a mentor for several graduation students.

Research activities

From a technological perspective, the two main questions to be answered during design are (1) does it work? and (2) can it be made? In practice, answering these questions always involves making trade-offs, for instance between cost and functionality. Erik is interested to find out to what extent the Medisign domain makes particular requirements regarding the second question and how production technology can generate solutions instead of problems.

Other activities

As of January 2007, Erik is the secretary for the Dutch Royal Society of Engineers (KIVI/NIRIA), department of Industrial Design. He is also an accomplished classical guitarist, performing regularly.