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Design is one of the basic skills of every engineer. However until now design is only seen as a core course in Architecture studies and lately in Industrial Engineering studies. This paper reports about the development of a design course for all departments of a typical technical university. After a short overview of design teaching tradition, an inventory is presented of the different interpretation of design by the various departments. The course development is presented over two periods: 2012-2014, and 2014-2015. In between a major change was conducted. The course learning goals and student evaluations are presented. In the discussion we reflect on fundamental and practical problems that occur in design teaching for such a wide audience. Finally we draw conclusions on the changing role of design what is needed to give design the same status as mathematics in a technical curriculum.

Keywords: Design, Design teaching, Multi-disciplinary design.

1 Introduction

University's education is in constant change. Updating courses to cope with future needs and challenges is part of being an academic. Educational changes not only apply to the course content but less frequently also to the educational system. Educational systems are in return part of an even bigger societal system and based on education principles, which are also due to change. In Europe universities programs are harmonized according to the Bachelor (3 year)-Master (2 or 1 year) program structure since the Bologna declaration of 1999.This major change in Europe now starts to yield effect through an increasing mobility of students between European universities. However, the structure of Bachelor programs can differ significantly.

Another trend in European academic education that lasted many decades is the lack of appeal of technical studies. Many children that potentially were qualified to choose a technical study decided to go to another university (economic, managerial) because they felt that the provision at the other universities was better, namely after graduation a higher salary with less effort. Due to the economic crises in Europe since 2008

Gabriela Celani, David M. Sperling and Juarez M.S. Franco (Eds.): The Next City: 16th International Conference CAAD Futures 2015, pp.37-46, 2015.

however, this trend has changed. Over the past two years the influx of students at technical universities has increased 10-20%.

In 2010 the Eindhoven University decided that a radical change was needed in their Bachelors program. Although the Eindhoven University's education was ranked in par with the best in the world, there were two main reasons for a change: (1) The foreseen increasing need for engineers, and (2) the foreseen need of engineers with technical and non-technical expertise. The first ambition, namely to educate more engineers is closely related to the second one, namely to educate a new type of engineer. Until then, the Eindhoven Universitycontained the traditional engineering studies (e.g. electrical engineering), the fundamental science studies (e.g. mathematics), the design studies (e.g. architecture) and the management studies (e.g. Industrial engineering). For today's challenges however, an engineer needs knowledge and skill from a mix of these studies. Accordingly, the Bachelor program was restructured such that a student has much more freedom to choose courses from other studies than his/her major study. As a side effect it was anticipated that this program also will attract a wider variety of schoolchildren. Not only those that are interested in technical engineering, but also students who have an interest in human and management subjects.

An import part of the new Bachelor program was the establishment of five Basic courses that are compulsory for all students, regardless which major study they are enrolled. The university board decided that the basic courses should reflect the basic skills of the future engineer. These five Basic courses are: Mathematics, Physics, Modelling, USE (User, Society and Enterprise) and Design. The first two courses come to no surprise, but the last three courses are new. The Modelling course aims at the conversion of technical design problems into forms that can be evaluated as mathematical expressions. The USE course aims at examining technological dilemmas from the perspective of humanities, history and ethics by questioning the role of the engineer. The Design course aims at learning design principles, processes, activities, and approaches by working on a design project.

The lead in the development of the new basic courses was allocated as follows: Modelling – departments of Industrial engineering & Innovation sciences and Mathematics & Computer science; USE – Industrial engineering & Innovation sciences; Design – departments of Built Environment and Industrial Design.

In this paper we focus on the development of the Basic Design course. In the first section we briefly discuss traditional methods in design teaching, followed by an overview of design perception and interpretation through different departments at a technical university. The course design section presents the considerations, implementation and evaluation of the first course that ran from study year 2012-2013 till 2013-2014 for an average number of 1200 students. The next section shows the changes that were made and the most recent experiences by the different groups of students in study year 2014-2015. In the discussion section many issues are discussed that we have experienced during the implementation and execution process. Finally, we draw conclusions with regard to the role of design in future academic teaching.

2 Design teaching

Teaching design has a long tradition in design studios. For many years architecture was the predominant design discipline in the academia. Architectural students are trained in a studio setting under supervision of a professional architect. Students work for one semester on a specific design subject. In the studio at the university campus students design is commented during the semester and at the end the complete design is presented and evaluated by the supervisors. Throughout the architectural study the design subject complexity will increase until the final graduation project. The teaching method follows closely the master-apprentice principle. Parallel to the design projects, courses are lectured on architectural theory and engineering. The knowledge gained in the courses support the design projects in the studios.

Relatively recent, industrial design has entered the academia. Industrial design has developed its own methods and techniques, but also embraced the design studio as the main environment for design teaching. In other engineering disciplines such as mechanical engineering and electrical engineering, design is seen as part of the engineering process and not as a core skill. Computer aided design has not effected design education substantially. CAD training is often only a side track of the studio work and CAD skills are learned by doing.

In contrast with the Basic courses Mathematics and Physics, there are no teaching handbooks for design on the academic level. Architectural design books are mostly only presenting architecture, but hardly any insight on the design process. Many well knowns researchers like Bryan Lawson [1] and Donald Schön [2] have researched design cognition and thereby also touched upon design training. Other researchers have proposed methods to capture the complexity of the architectural design process (John Habraken, Herbert Simon, Christopher Alexander). Design methods have raised fundamental discussions amongst academics and between academics and architects. Design methods were often not widely adopted in architectural practice, but only seen as a scientific abstraction. That is most likely one of the main reasons why architectural design handbooks do not exist. Industrial design has brought forward a number of influential books in the industrial design process [3] and design teaching [4]. Industrial design as an academic discipline is developing itself more rapidly than architecture with its traditional roots. Last but not least there exist many books on engineering design with a basis in mechanical engineering. These books show remarkably resemblance which shows that in this field there is a strong common understanding on what engineering design is and how this should be taught (see e.g. [5]).

In scientific journals like Design Studies, European Journal of Engineering education, International Journal of Technology and Design education many papers are published on the effect of different course structures on students' design performance (see e.g. [6], [7], [8], [9]). However these studies focus on a single discipline (e.g. architecture) or on multi-disciplinary design, but only within the boundaries of one department or one major study.

Design has a very broad meaning inside and outside a technical university. For our university we agreed upon the following definition for a design artefact:

- Physical product, like a building or coffee machine
- A system, like a software system or an organization
- A service, like a customer service or a public service

Even then, the interpretation of what design is amongst the different departments is diverse. Below a brief description is presented for each department in alphabetical order:
Applied physics: Design is not a special topic in the applied physics curriculum. Physicists do design experimental setups but these are usually not considered an end product.
Biomedical engineering: Biomedical engineering is built upon other departments and therefore not discussed separately here.
Built environment: Design is core for the whole curriculum and has a focus on spatial design ranging from building components to landscape.
Chemical engineering and chemistry: In chemical engineering design refers to design of chemical processes and its installations.
Electrical engineering: Design of electric circuits and automation system is a core component.
Industrial design: Design is core for the whole curriculum and has a focus on user experiences of the design artefact.
Industrial engineering and Innovation sciences: Design of services and organizations is recognized as a design process.
Mathematics and Computer science: In computer science software design is a core topic supported by well-founded methods and techniques.
Mechanical engineering: Engineering design has its basis in mechanical engineering and has a focus on the assembly of parts.

From the short descriptions we can conclude that different interpretation exists with regard to design phenomenon, namely:

- *Design as a product or as a process*

Although for some departments, design of a product, system or service might not be a major topic, nevertheless design as a process occurs everywhere.

- *Design at different levels of scale*

Design ranges from quantum physics level to regional planning level. Multi-level design and engineering is still quite rare.

- *Design at different levels of abstraction*

Product design results in tangible products, whereas system design and service design are not tangible, but will become so after implementation.

- *Design as a deterministic or a non-deterministic process*

For some departments design is an open ended, creative process, whereas for others design is a closed, solution oriented process.

In the following two sections we describe the design and evaluation of the basic design course of two episodes that subsequently ran over the study years2012-2013 till 2013-2014, and 2014-2015. The first episode was focused on design theory, and the second episode was focused on design skill. The descriptions are kept relatively brief using factual data, while in the discussion section we present our personal observations based upon discussions with students and teachers.

3 Course design: Theory-based

The learning objectives of course the in the first episode were defined in three components:

1. Knowledge component. Students:
    - gain knowledge about and see relationships between design principles, skills, approaches, context and quality, including different perspectives on design;
    - learn the (variety of) vocabulary within design to enable communicating within the own discipline and between disciplines;
2. Skill component. Students acquire design skills to:
    - generate ideas and concepts based on previous findings and objectives;
    - evaluate a design in various stages of the design process;
    - learn to reflect in and on own design actions and process;
3. Attitude component. Students show:
    - inventiveness: the designer questions and open ups the situation at hand in the move towards a design solution
    - openness and receptivity towards other than one's own discipline

The course consisted of two parallel tracks running over eight weeks, namely one track of weekly lectures with accompanying assignments and one track of working on a design assignment. The weekly lectures covered the following design topics:

- Design in a nutshell
- Design specification
- Design methods and techniques
- Design evaluation
- Design visualization & representation
- Design management and business

In the first week's assignment students were asked to write down a design need or challenge. In the following weeks new design methods and techniques were introduced in the lectures. In the weekly assignment they reflected upon a chosen methods or technique for their need/challenge. The weekly assignments were peer-reviewed by three fellow students. The lectures were supported by slides and a thesaurus containing design terminology with its definitions.

Parallel to the weekly assignments, students worked on a design assignment. Therefore they could choose from three different types of assignments

- High Tech Systems
- Integral design
- Social innovation design

The assignments were all aiming at a product, but they differed in scale, abstraction, process, and group size. In the High Tech Systems project a wave stepper robot was designed in groups of two students using SysML modelling language and simulation tools. In the Integral design project students worked individually on low-carbon building using 3D modelling and energy simulation tools. In the Social innovation design project, students worked in teams on innovations that promote human health. The design projects were concluded with a general meeting of all students with a contest for the best design of the year.

The most important outcomes of the questionnaire that was sent to the students shortly after the end of the semester are:

1. Discrepancy between theory and project
2. Relevance for study not recognized
3. Peer review not appreciated

Students felt that only a small part of what was learned in the lectures could be applied in the design project. They did not see the relationship between the design methods and techniques and the design assignment. Large groups of students especially from those departments where design is not a major topic considered the course ‘a waste of time’, because it did not contribute to their education. Finally the peer-reviewing system was not highly valued especially not by the strong students because they received only poor comments.

4 Course re-design: Skill-based

The learning objectives in the second episode of the basic design course are divided into:

1. Individual learning objectives
   - Set and accomplish a measurable and/or experienceable individual design goal;
   - Use specific design methodologies in a project and develop his/her own view of the merits of this methodology;
   - Show an attitude of inventiveness, dare and responsibility towards his/her design part/aspect;
   - Show openness towards integration of design parts/aspect from another than his/her own discipline.

2. Team learning objectives
   - Set and accomplish a measurable and/or experienceable team design goal;
   - Reflect upon various views of and methodologies for designing that are typical for the engineering professions in a design team;
   - Communicate the design and design process using the general design vocabulary from the thesaurus;
   - Integrate different design parts/aspects in the group process/design.

Because the overall student evaluation of the initial Basic Design course was poor and below the university’s standard, a major change was deemed necessary. The educational programs directors of the departments concluded that that course should be based on the well-known design driven education paradigm. Essential in this paradigm is working in multi-disciplinary design teams under supervision of a tutor.

Consequently the course was restructured as follows. Students are allocated in teams of five students, ideally all from different departments. In the first week there is a general introduction to the course and the team specifies the design subject together with their tutor. In week 2 and 3 students follow one of the following workshops: (1) Ideation & visualization interactions, (2) Systems engineering, (3) Spatial design and energy performance, (4) Design prototyping. Ideally students from one team follow different workshops. From week 4 onwards, the students work as a team on their design subject using the knowledge from the workshops. A study guide describes the weekly deliverables for the team as a whole and for the student as an individual. At the end of the semester a team design report is submitted and an individual report on the his/her own design part/aspect and design process. In a final general lecture the best design was selected from all student teams.

The most important outcomes of this year's (2015) questionnaire is:

1. Students appreciated working in multi-disciplinary teams
2. The workshops sometimes did not match with the chosen design subject
3. The weekly program was either too vague or too strict

Students appreciated the opportunity to meet and work with students from other departments. The workshop skills were not always applicable to the design subject chosen in the first week. The problem was caused by a difference in scale and abstraction. Differences in attitude between students caused difficulties in the design process. Designerly oriented students prefer an open, creative process, whereas fundamental science students are frustrated about the vagueness of what is expected from them.

5 Discussion

During the development of the course and while running the course many issues were discussed between the responsible departments and between teachers and students. First we will discuss the more fundamental issues and then the practical issues.

Fundamental

There is no common understanding about design nor design teaching. The fundamental differences between the departments presented above were apparent right from the start. Therefore it was decided that students should be confronted with multiple design approaches, instead of a single generic approach. The downside of this standpoint is that it is almost impossible to structure the course. In the first episode of the course students complained that the lectures did not synchronize with the design projects. Design theory was learned too late or was not applicable at all. In the second episode a very basic structure was implied namely: specification, concepts, evaluation, refinement, finalization and presentation. Dependent on the tutors background (i.e. the department that he/she was recruited from), this basic structure was followed or neglected, leading to confusion among the students.

In both episodes teaching design methods and techniques is part of the course. In the first episode this was established through lectures, in the second episode through workshops. One could argue to implement the complete course as a design studio with tutoring and no class room teaching. However, most departments feel that students in their bachelors don't have enough expertise to substantially contribute to a design project. On top of that, even now groups of students complain that they 'did not learn a lot'. Technical students' cognitive talents are not well enough challenged in a design project. A tutor could take care of the design knowledge transfer, but whereas we concluded that there is no common understanding about design this applies also to tutors.

Multi-disciplinarity can be implemented in the course in different ways. In the first episode students from different departments subscribed to of the three assignment types. Every student followed the design approach that fitted that assignment type. The High Tech Systems assignment was highly structured while the Social innovation design assignment was very explorative, and the Integral design assignment was in between. Collaboration between students was sometimes promoted but not always. In the second episode students worked in teams stemming from different departments. Moreover they followed different workshops and they were requested to apply the workshop skills in the team project. In the latter situation the tutor plays an important role in finding a design subject that allows every student to use his/her workshop skills. Due to differences in scale and abstraction between the workshop this turned out pretty hard sometimes.

Groups of students debated the relevance of the design course for their major study. An easy solution to this problem is to have every student follow a workshop that is offered by their own department. As a consequence the problem of integrating different workshops into one design will become even harder. One step further every student follows the complete course in his/her own department with teachers and a topic that are familiar. In that case one could argue that course does not deserve the name Basic course anymore, because every department is teaching its own design course without any common part.

Groups of students requested a course structure, results and grading that leaves no room for ambiguity. This request is in sharp conflict with the nature of design. In principle a course could be designed such that all students work on the same assignment, following the same instructions, resulting in the same design. Even though these groups of students would probably appreciate this course structure, the responsible teachers feel that challenging especially these students to step out of their comfort zone, is one of the most important objectives of this course. Thus ambiguity should be part of a design course despite the frustration that it causes.

Practical

Teaching approximately 1200 students is a logistical challenge. The largest class room at the TU/e has 300 seats and for the design studios a lot of floor space is needed. The administration of students, student teams, workshop and the room scheduling demands much labor. The distribution of course material and submission of reports requires robust automation systems. The upscaling from courses that would fit in one class room to courses with 12 students put a lot of stress on personnel and facilities. To overcome some of these issues the following measures were taken.

The lectures that were given in parallel class rooms linked through video connections in the first episode were largely skipped in the second. Students stayed away from these lectures and instead watched the video recordings. In the last episode of the course only the first and the last lectures are general and compulsory for all students. The other lectures about design methods and techniques were recorded as web lectures of 5-10 minutes. Students can watch these web lectures as input to the design project.

Students turn out to be very sensitive to course organization. This applies to the structure as well as to the technology. If course information is not easily accessible or even worse not clear, then frustration arises quickly. Even so, if systems fail or give unexpected messages, then students' tolerance is low. Although these matters of course should not hinder a student in his/her work, sometimes problems are simply out of control of a teacher. Evaluations however show that these frustrations have a high impact on the overall appreciation of a course.

The peer-reviewing procedure worked relatively well technically but was not highly appreciated by the students. To ensure consistency and prevent abuse, a sample of all reviews and scores by fellow students was checked by teachers. The students' reviews and scores turned out to be very consistent with the teacher's scores. However, especially the strong students were unhappy with the peer-reviewing. They were disappointed by the reviews they received because on average they were below their own standard. In general students like teamwork but they don't like they idea of learning from each other. They came to the university to learn and receive feedback from scientists. In the workshop in-depth design knowledge is conveyed by staff members and can be tested through assignments. In the design project for practical reasons we involved student assistants that have less design experience. Even more important, students desire clear cut criteria for evaluation of their work what is in conflict with the open-ended nature of a design project.

6 Conclusion

The main conclusion at this time is, that design as a core skill for a Technical University Master is not yet recognized by all students. A comparison with the Basic Mathematics course (Calculus) can illustrate this. A student from the department of the Built Environment will never question why he/she should follow a Basic course Mathematics. Before coming to the technical university he/she knew that this is part of the education. In contrast many mathematics students question why they should follow a Basic course Design. For them a design course comes as a surprise, and they cannot understand the added value for their education.

Insisting on the idea that design is something that is behold by the creative genius will isolate the designers from the engineering disciplines. Instead design serves as an integrator between disciplines. A uniform language is needed that allows designers and engineers to communicate. Intriguing in that regard is the development of a relatively young discipline of Computing Science. In a few years a standard language (UML) and an standard book with code samples [10] was developed that is accepted widely in science and practice. Interestingly many of the terms were adapted from architecture, such as system architecture and design patterns. Due to the mathematical background of many software scientists, this field succeeded in explicating their knowledge in a uniform interpretable way. Similar steps are needed for expressing design concepts and communication between engineering disciplines.

On top a uniform design language, uniform criteria for design evaluation are needed. These are a combination of qualitative and quantitative criteria, dependent on the design subject. Interestingly, this demand for evaluation of design and design alternatives is also expressed by professional clients in design and engineering practice. In education the tradition still holds that we should not limit our students' creativity with the technical and financial constraints of today. This approach seems not realistic anymore. Design is a constant process of decision-making. Only if we demand explicit decision-making by students in their design project and by teachers (or tutors) in their evaluation, then discussions about design quality becomes manageable. Today in education we observe that the use of rubrics for evaluation of work becomes a standard technique that also will objectify design quality.

Design is not anymore the privilege of only a few departments of a technical university, but it will become as basic and as normal as mathematics or physics to any technical student. Design can only deserve that position if it explicates itself in a formal way and if it is recognized by all disciplines as essential for complex engineering tasks.

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