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Engineering Education 2.0: the Eindhoven Case

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In response to complaints from industry in the 1990-s that engineering graduates had been educated too theoretically, Eindhoven University of Technology first developed the concept of Design-Based Learning, which was successfully implemented from the year 2000. More recent developments, both globally and locally, necessitated a more fundamental reform of all TU/e education. In 2012 a totally new design of BSc education was put in place, with encouraging results thus far. More reforms, including graduate studies, are underway.

Key words: *engineering education, professional skills, educational reform, curriculum design.*

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Engineering Education 1.0: The classical approach

Following decades in the 20th century during which industry seemed to be perfectly happy with the engineers graduating from university, during the 1990s the first complaints from the corporate world started reaching the universities of technology in the Netherlands. University-educated engineers were considered to be theoretically strong within their own academic discipline, but lacking in practical skills, in solving problems and in an integrated, multidisciplinary approach. Hence, additional in-company training was required before university graduates in engineering would become truly useful with an industrial setting.

If we look back at engineering education as it was in the 20th century, a number of characteristics stand out:

- All education was based on the academic discipline in question, e.g. Mechanical Engineering, Electrical Engineering, Applied Physics.
- While students did have occasional practical labs, they spent most of their time sitting in lecture halls, taking in what their professors were telling them.
- Individual subjects were typically taught separately by individual professors. Integration of subject matter was left to students.
- In general, students had a fairly passive role in their education. They were expected to take notes during lectures, study literature and display mastery of subject matter during examinations with an emphasis on reproduction of knowledge.
- Theory and practice were strictly separated. Practice consisted of isolated lab work and perhaps an internship, and that was that.
- Studying engineering was a strictly individual affair. Co-operation in groups was rarely, if ever, required.

In view of these characteristics – let’s label them Engineering Education 1.0 – the complaints from industry could hardly have come as a surprise. What engineering students were confronted with was essentially a large pile of individual theoretical subjects which

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they were required to reproduce, without much attention being paid to labour market requirements.

Engineering Education 1.1: Design-Based Learning

At Eindhoven University of Technology (TU/e), by the end of the 1990s it became clear that something needed to be done. In order to deal with the criticisms from industry, the university adopted a new concept called Design-Based Learning (DBL). While classical elements of engineering education were retained, engineering students in the new millennium would now spend roughly one third of their time in DBL-type education.

Now what would DBL entail? Nationally renowned professor of education Wynand Wijnen was hired to work on this issue. What he came up with, was not a single teaching method, but a number of characteristics a certain curriculum part would need to have in order to be called DBL.

The six DBL characteristics (Wijnen, 1999; Wijnen et al., 2000) include:

1. Professionalisation: design-based learning should be profession-based rather than driven by the structure of the academic discipline. There should be more cohesion with the field and learning should be more practical and application-oriented than traditional engineering education.

2. Activation of students: students would be required to act more rather than sit back and wait what's in store for them. They would have to show more initiative rather than just follow prescribed rules, and spend more time in small groups rather than large anonymous crowds in which non-participation isn't easily noticed. Hence learning becomes more demand-driven rather than the traditional supply-driven approach.

3. Co-operation between students: more working in teams rather than individually, in less homogeneous groups in which students are more mutually supportive and complementary, rather than everyone for him- or herself according to a uniform mould.

4. Creativity: more original and productive work, rather than reproduction of standard knowledge; more emphasis on developing new solutions than on application of already known solutions; more divergence in approaches rather than convergence.

5. Integration: theory and practice combined rather than separated; more emphasis on relations between subjects rather than on separate subjects; more theme-based learning rather than by individual subject; more team-teaching instead of individual teaching.

6. Multidisciplinarity: surpassing individual disciplines, more thematic rather than per individual course; encompassing more engineering disciplines rather than within a single discipline; more holistic rather than atomistic.

Please note the function of the phenomenon of design in all this: DBL does NOT mean that students are taught a course in which they learn to design. It means that designing is a process which lends itself very well for application of the six characteristics mentioned above; hence students learn in a design-based way through the process of designing. In short: design is a means here, not an end.

In the year 2000, implementation of DBL within the Eindhoven engineering programmes started. It soon became apparent that there was a wide variety in the ways DBL was conceived and implemented by the individual disciplines, departments and programmes within TU/e. One size did not fit all. For instance, in the Industrial and Applied Mathematics programme, settings in which pairs of students work on modeling assignments became the preferred way of implementing DBL, whereas disciplines such as Mechanical Engineering had students work in small groups of 6-8 students on projects derived from practice. This variety was deemed a good thing; the intention never was to impose a single pedagogical model in a top-down way.

While the implementation of DBL started hesitantly and a fair amount of internal resistance to change had to be overcome, after a few years DBL-type teaching and learning methods could be found throughout the university (as noted before: always in combination with more classically taught curriculum parts). Engineering Education 1.1 was a fact.

Evaluation of DBL

In 2007, discussions were held with all BSc programme directors in order to informally evaluate the results of DBL until then (Peters, 2007). The programme directors were unanimous that the characteristics professionalization, activation, co-operation and creativity had been successfully incorporated into TU/e education through DBL. The integration and multidisciplinarity aspects turned out to be more difficult to implement. Whereas initially assessment of group work at the individual level was found to be difficult, over time different ways to tackle this issue had been developed, often by including peer review among students in the overall assessment. This was also used to deal with free-riding behaviour within groups of students.

DBL was found to stimulate students to work hard and spend much time on learning, sometimes at the expense of more classically taught subjects. In general, students were satisfied or even enthusiastic about DBL.

Programme directors unanimously agreed that DBL was to be continued and developed further.

A more recent analysis, using the ACQA (Academic Competences and Quality Assurance) framework developed at TU/e (Meijers et al., 2005), has demonstrated that DBL courses scored significantly higher on all DBL aspects except integration than non-DBL courses (Perrenet & Van de Wouw, 2013). Differences between DBL courses were mainly in the area of multidisciplinarity. Additional analyses showed a contrast between DBL and non-DBL courses in the relative weight of different areas of academic competence, with DBL courses emphasizing synthesis, design, co-operation and communication, and non-DBL courses showing more focus on intellectual basic skills, the scientific approach and abstraction, with disciplinary competence always at the forefront.

Thus, a fair balance between various relevant academic competences seems to has been struck through the introduction of DBL.

New needs and new challenges

Part of the mission of TU/e is to educate new generation of future-proof academic engineers, i.e. engineers who are able to make a significant contribution to society ten, twenty or forty years into the future (Meijers & Den Brok, 2013). Nobody is able to predict with any degree of certainty or accuracy what our society will look like in the future, which is why engineers will have to excel in a number of generic competences, necessary regardless of what the future holds. The American National Academy of Engineers (NAE) developed four scenarios for the future development of the world (NAE, 2004):

1. The Next Scientific Revolution, with technology as a driving force for future change.
2. The Biotechnology Revolution, with the social and societal impact of technological innovation and attitudes in society as key issues.
3. The Natural World scenario, in which forces of nature are determining mankind's future, with a role for engineers to predict and develop methods to handle natural events.
4. Influence of Global Change, in which globalisation and world-wide challenges are key.

Since no one can predict the future and the world will probably facing a mix of these scenarios, a university of technology's job is to educate engineers in such a way that they are able to play a meaningful role in each of the NAE scenarios. This has led TU/e to the conclusion that the engineer of the future does not exist and that different types of engineers should be educated (TU/e, 2011).

While it is true that the future is largely unpredictable, some more robust and predictable developments can also be identified (Meijers & Den Brok, 2013). One such trend is that technology is playing an increasingly important role in people's private lives (mobile phones, Facebook, Twitter etc.) Technology has developed an enormous breadth over the years – a good example is the increasing role of technology in health care.

Another clear trend is internationalization, and partly in conjunction with this, more diversity in types of students.

The landscape is thus changing rapidly when it comes to educating "the engineers of the future". "The rise of smart machines, a globally connected world, superstructured organisations and emerging new technologies will all have their influence on higher education in general and engineering education in particular. Engineers of the future need to be able to make connections with ever expanding frontiers of science and technology and different fields of expertise and use this knowledge and these insights in their work. This holds for aspects like behavioural influence and social cohesion, but also for what we can learn from nature." (TU/e, 2013).

Against this global background, TU/e has been facing some serious challenges of its own in recent years:

- Insufficient student intake to meet the demand for engineers in the corporate world.
- Decreasing market share, with a perspective of unfavourable demographic prospects in the region (lowest birth rates in the country), which could well lead to further decline.
- Low success rates of students who on average take too long to complete their studies (around five years ago, only around 32% of the students who continued their studies after the first year managed to complete the 3-year BSc curriculum within four years).
- A problem found throughout Western Europe was (and still is) – and unlike the situation in the Russian Federation, as far as I know – the low interest among females in studying engineering. While participation of girls was well below 50% in all TU/e engineering programmes, at TU/e especially in Electrical Engineering and in Computer Science no more than 1 or 2% of the student population consisted of girls.

In combination, these factors started to form an existential threat to the university. If nothing would be done, the future student base would become so small that it became questionable whether TU/e would be able to survive in the long run.

In the face of these massive challenges, both global and local, TU/e has chosen to undertake the most fundamental educational innovation in its history, the outlines of which will be described below.

Towards Engineering Education 2.0: the Eindhoven approach

A dedicated Task Force was established which should develop a fundamental re-design of TU/e's Bachelor programmes, with a view on making them attractive and accessible to a larger group of students, taking into consideration the different types of students that might be interested in studying at TU/e.

Some research on the latter issue had been done in 2007 (YoungWorks, 2007), which had resulted in the so-called "BètaMentality model". This model divided adolescents into four categories:

1. concrete bètas: intrinsically motivated by technology;

2. career bètas: motivated by career perspectives;

3. human oriented generalists: want to contribute to solving problems in society;

4. non-bètas: little to no motivation to study science and/or technology.

Further studies demonstrated at no less than 66% of TU/e students consisted of "concrete bètas", whereas this group only comprises 17% of the total population of students in Dutch university-preparatory education. These findings suggested that large groups of students potentially interested in science and technology were so far not attracted by TU/e.

The TU/e Task Force presented its final report in May 2011 and presented far-reaching recommendations which were followed to a large extent. All TU/e bachelor programmes would in future be offered under the umbrella of a TU/e Bachelor College, headed by a Dean. All programmes would have a common curriculum structure, which is shown in the following figure (unfortunately in Dutch) (Fig. 1).

A Dutch academic Bachelor programme comprises a total of 180 credits (EC). In the new TU/e BSc model:

- 90 credits (shown in light blue) are devoted to a major, chosen by the student
- 45 credits (shown in red) are devoted to electives
- 30 credits (shown in orange) are devoted to institution-wide basic courses
- 15 credits (shown in dark blue) are devoted to "USE", which means User, Society, Enterprise.

The 30 credits that all TU/e Bachelor students should spend in basic courses comprise 6 institution-wide common courses, and thus represent a common body of knowledge of all TU/e BSc graduates. These courses include (Fig. 2):

- Maths
- Applied Natural sciences
- Modeling
- Design
- User, Society & Enterprise
- Professional skills

with a study load of 5 credits each.

Fig. 1. General curriculum structure

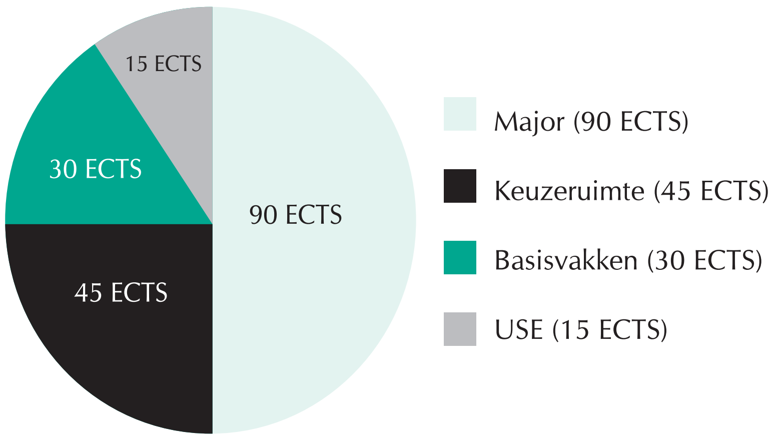
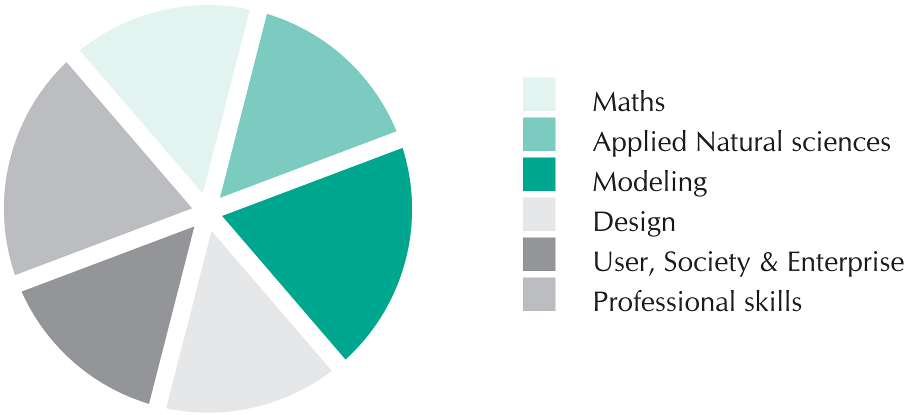


Fig. 2.



Professional skills are taught integrated in the curriculum of the major the student has chosen; in our experience learning these works best when related to subject matter and not separately.

The relatively large amount of electives in our new BSc model is related to TU/e's conviction that it needs to educate different types of engineers: while many students, like before, will opt to go in-depth as much as they can (especially the so-called "concrete betas"), other categories of students can combine various interests into a broad package of subject matter if they choose to. This should appeal to both "career betas" and "human oriented generalists". Other measures were taken as well.

- Professors were to perform a new role as well: coaching students in the many choices they would be required to make in the new model.
- Curriculum units should be 5 credits, while in the past they tended to be smaller.
- Intermediate examinations were introduced to provide early feedback to students on their performance.
- No more than three units should be taught simultaneously (in the same term), preventing the competition for the students' attention among too many course units.
- A maximum of 24 hours a week was introduced for in-class activities. In the past, some programmes were overburdened leaving the students virtually no time for independent study.
- Teaching methods should activate students as much as possible.
- Majors were developed in new, mostly interdisciplinary, areas, including Automotive Technology and Psychology & Technology.
- Existing honours programmes were completely restructured into the TU/e Honours Academy, which offers extra challenges to the very best students.

The new curriculum model took effect in September 2012.

First results

After a little over a year, the first results of the new BSc model are encouraging. The past two years have witnessed a significant increase in student numbers, about 15% per year. The traditional TU/e student intake, the concrete betas, have not been deterred by the new curriculum design, whereas specially "human oriented generalists" have come to TU/e in much larger numbers than before. The start of the TU/e Bachelor College resulted in a 50%

increase in female first-year students. In the new design, students perform better as well: less drop-outs, better study progress. Student evaluations revealed that students found their studies to be interesting and challenging. On average they rated their studies 7.25 on a 10-point scale. Of course, the new design had its flaws as well; especially the design of the common basic courses needs further attention.

At present, the transition at TU/e is still ongoing, with many more challenges to come. The second curriculum year is now being taught for the first time, the third year is still "under construction". And that is merely the undergraduate education. For its graduate education (comprising two- year MSc programmes, two-year Technological Designer programmes leading to a Professional Doctorate in Engineering (PDEng) and four-year PhD programmes), TU/e has established the TU/e Graduate School, in which these 3 types of programmes are brought together in a coherent way. Reforms for the graduate phase of TU/e education are still being developed as we speak. Core elements are likely to be:

- more attention to professional skills
- more international students
- establishment of a true academic community
- more MSc students continuing to pursue a PDEng or PhD degree
- extra challenges for excellent students
- transparent quality assurance in the PDEng and PhD
- better success rates.

While it is obvious that all these fundamental reforms are putting strain on the TU/e organisation and its academic and support staff, it is equally obvious that the aims of the reforms are worth the effort. Hopefully the encouraging first results will be followed by many more to come!

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