Engineers for the future: an essay on education at TU/e in 2030

Technische Universiteit
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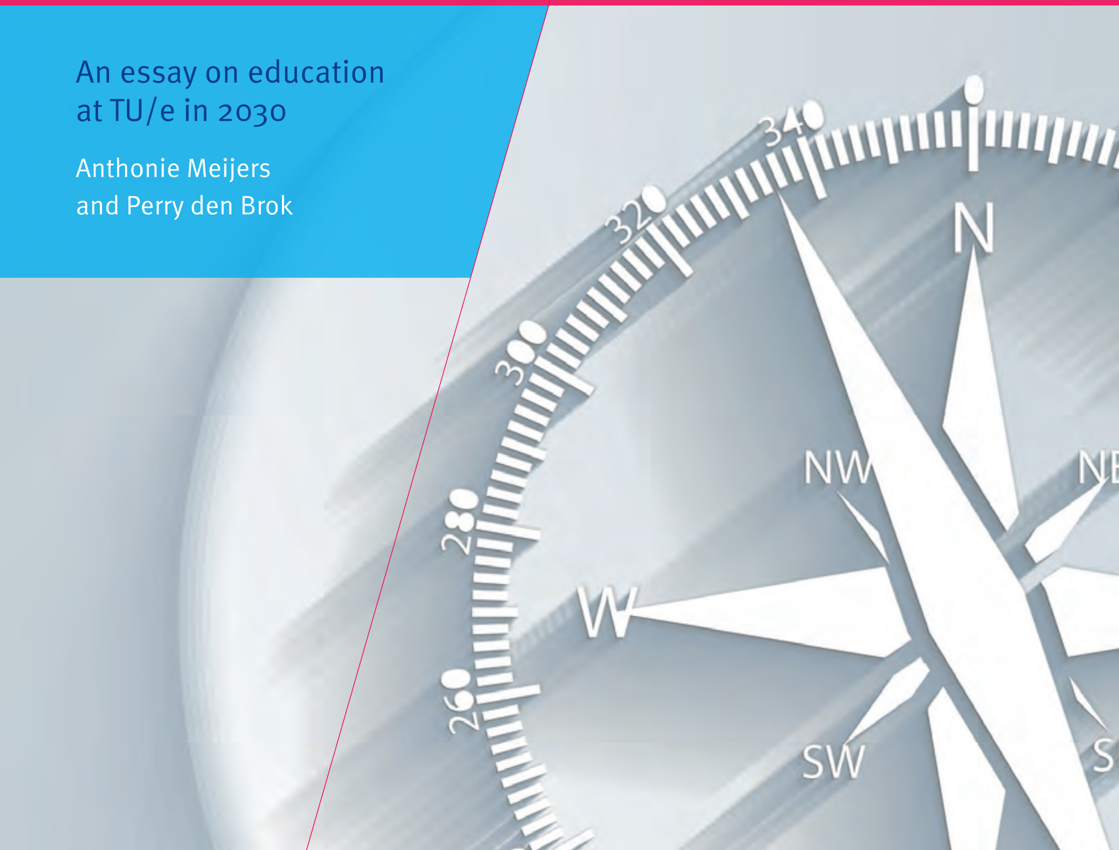
Anthonie Meijers
and Perry den Brok



Where innovation starts

Colophon

Authors
Anthonie Meijers and Perry den Brok

Title
Engineers for the Future

Subtitle
An essay on education at TU/e in 2030

A catalogue record is available from the
Eindhoven University of Technology Library

ISBN: 978-90-386-3478-4

Eindhoven, 2013

Photography
Norbert van Onna

Graphic design
Volle-Kracht, Eindhoven

Print
Drukkerij Snep b.v., Eindhoven

Content

Foreword

Students are the reason a university exists. All our skills and creativity are poured into the training of engineers, researchers and designers. Even our research is geared toward preparing a new generation for the future.

This essay sets out the intellectual foundations of our educational policy. And it explains the transformation we have brought about in our students' educational program over the last few years. Our Bachelor College and Graduate School have been fundamentally altered to prepare engineers more effectively for their role in society. The essay also lays out the direction of new policy in areas such as the digital university, ICT in education and lifelong learning.

The future of our engineers is multifaceted: there is no such thing as the engineer of the future. Some will qualify in a single discipline and help push back the boundaries of our knowledge and capabilities. But society also needs engineers for whom technology is a means to an end. For such engineers studying a technical subject offers an excellent foundation for future work as teachers, doctors or managers. Other engineers will be generalists working in an interdisciplinary environment on themes that, like energy, health and mobility, are of great importance to society.

Our new Bachelor College and Graduate School are every bit as multifaceted. Engineers at Eindhoven are trained according to a common philosophy and on a common basis. They take in mathematics, physics, technology, design, professional skills, humanities and social sciences. This prepares our students for a wide spectrum of roles, while simultaneously laying solid foundations for specialization. Considerable flexibility now exists in the choice of subjects, so that students can decide whether to dig deeper or to combine elements of different disciplines. In this way they can concentrate on what is genuinely important in developing their own talents and careers.

I am delighted by the lucid and insightful way in which my colleagues Anthonie Meijers and Perry den Brok have set out this educational vision. I offer them my sincere thanks. The authors also fulfill key roles in the educational debate at our university. Ongoing debate of this kind is vital, as we cannot know how the world will change. No doubt there will be fresh technical breakthroughs and new problems for us to confront. This essay inspires us to keep education at TU/e firmly at the forefront of our concerns so that we can continue to achieve our ambitions in the future.

Prof. Hans van Duijn, Rector Magnificus

Short summary

Engineers for the Future

An essay on education at TU/e in 2030

Anthonie Meijers and Perry den Brok[1]

TU/e's educational mission is to educate engineers who will be able to make significant and innovative contributions to society throughout their career. Based on this mission, the core values pursued by TU/e, and an analysis of the chief trends outside and within the university in the medium and long term, this essays develops a vision of education at TU/e in 2030 with respect to the following core elements:

- *The pursuit of excellence, in which the connection between education and research is the central pillar.*
- *Small-scale education and master-apprentice interaction as key components of academic education.*
- *Internationalization of the student population and a greater diversity of students.*
- *Teaching that is driven by student demand, with a stronger tutoring role for the teaching staff.*
- *An important role for ICT in teaching large groups of students and in lifelong learning.*
- *Professional development of the educators that transcends basic university teaching qualifications.*
- *Greater emphasis on multidisciplinarity.*
- *Greater emphasis on output qualifications in education and in educational quality assurance.*
- *In due course, a considerable expansion of TU/e education aimed at lifelong learning and a substantial involvement of the business world.*

These elements have played a role in the recent redesign of TU/e's bachelor curriculum and have been fully or partially implemented in the Bachelor College that was founded in 2012. They will also play a role in the further development of TU/e's Graduate School.

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1 *Anthonie Meijers is Professor of the Philosophy and Ethics of Technology and University Professor at TU/e, Perry den Brok is Professor of Educational Science for Science Education at TU/e. The authors are grateful for peers' comments on an earlier version of this essay.*

Introduction

"the role of engineers in society is likely to be very great"

1

On December 15, 1977 the first Holst Memorial Lecture was held at TU/e in memory of one of the most prominent founders of the university and the first director of the Philips Physics Laboratory, Professor Gilles Holst. At the time, the university was just two decades old. The speaker was Dr. Alexander King, informally associated with the 'Club of Rome' and director of OESO. The topic of his talk was: 'The role of the engineer and the engineering sciences in future society'. King summarized his lecture as follows:

'[...] the role of engineers in society is likely to be very great and the tasks facing him will be formidable. It will be necessary for him to work in a social, economic and cultural perspective, to be fully aware of political and societal constraints and to be exceedingly flexible. The ever increasing database of the profession will *inevitably favor a greater degree of specialization*, but the temptation must be resisted to cram more and more specialized courses into the curriculum or to lengthen the learning period of formal education unduly. Young engineers will have to be exposed to the real problems of society as early as possible and hence sandwiches of instruction and practice will be desirable. The creativity and inventiveness of research engineers should be a constant preoccupation of management and, for this purpose the inclusion of fundamental research scientists in applied laboratories is desirable. The problems facing society are indeed great and their solutions will depend much on acceptance by the public at large.'

Thirty-six years later, many of the issues put forward by Dr. King are still as pressing as they were then. The great challenges facing the world – particularly those relating to sustainability, economic stability and safety – as well as increased specialization in the engineering disciplines, the importance of fundamental research and of creativity, the societal and ethical responsibilities of engineers, the prevailing image of the engineering profession and the acceptance of new technology are still high on the agenda today.[2] They are a major reason for making, once again in 2013, engineers of the future the theme of the most prestigious academic lecture held at TU/e, the Holst Memorial Lecture.

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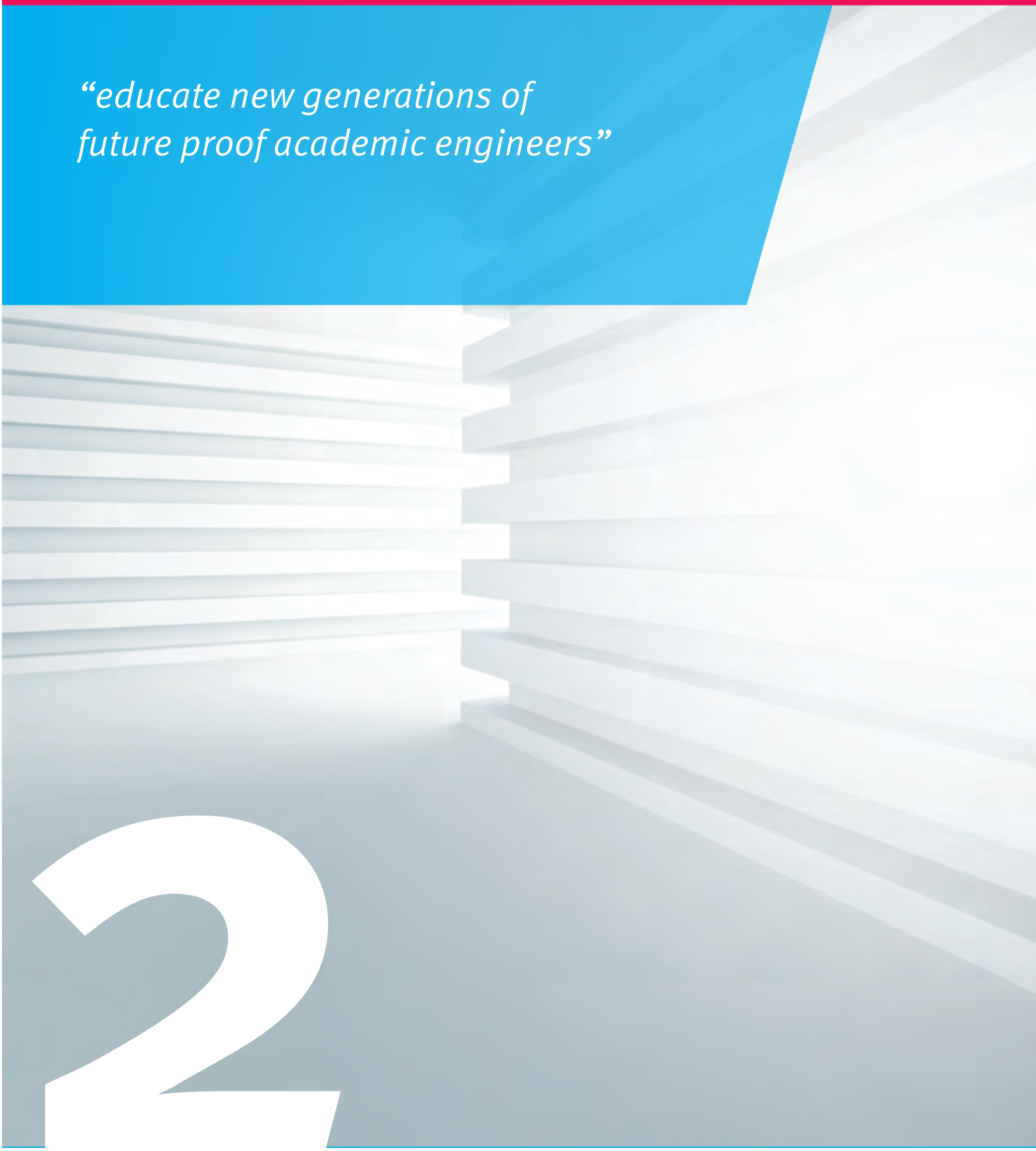
2 *See, for example, James J. Duderstadt (2008), **Engineering for a Changing World; a Roadmap to the Future of Engineering Practice, Research and Education**, The Millennium Project, The University of Michigan USA.*

The mission of TU/e

“educate new generations of future proof academic engineers”



2

The recurring concern with the future of the engineering profession illustrates the fact that TU/e regards itself as a university with a mission. This university of technology aims to educate new generations of *future proof* academic engineers, that is, engineers who are able to make a significant contribution to society ten, twenty or forty years into the future. Nobody is able to predict with any degree of certainty or accuracy what our society will look like in the future. That is why engineers will have to excel in a number of generic competences, i.e. competences that are necessary no matter how things turn out. Engineers of the future must be professionals capable of thinking critically and independently and must be able to keep developing and renewing their expertise throughout their career. Using state-of-the-art technology, they must be able to contribute to solving societal problems, but also to the development of new chances and opportunities. They must have an inquiring and creative attitude, a high degree of creativity and societal responsibility, as well as the ability to look beyond borders and to work as team players.[3] The world, after all, refuses to be divided neatly into academic disciplines.

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3 *TU/e has elaborated this profile in a system of academic competences. For this see Meijers et.al.,* ***Criteria for Academic Bachelor and Master Curricula,*** *Eindhoven 2003/2005. This also provided the basis for a system of quality assurance at the level of the curriculum (ACQA).*

Future developments

"technology which directly affects the way people think and act"

3

It is only partly true that the future is unpredictable. Some developments, such as demographic trends, can be confidently predicted. Political or economic developments, on the other hand, are very hard to forecast, certainly in the longer term. This is also true of a great many technological developments. To give but one example, when the World Wide Web was invented and the first web server was installed in 1990, nobody would have predicted that, 20 years later, 50 billion or so web pages would have been indexed by Google, a company which did not even exist in 1990, but which is now one of the largest technological companies in the world.

Nevertheless, more robust and predictable developments can also be cited. One of these is that technology has come to play an increasingly important role in the *private lives* of people. Whereas in the past, a telephone used to be a functional object hanging on the wall and allowing us to call others, it has now acquired the status of a ‘Life Companion’, something that is with us wherever we go and enables us to share, so to speak, all of our major and minor life events. Actively and purposefully, technology increasingly influences our social environment (via the Internet), our individual experiences and even the way we think and act (for instance by means of persuasive technology).

This trend offers a glimpse of the enormous breadth technology has developed over the years. On the one hand, engineers are developing technology that approaches the limits of what is physically possible (for instance in lithography). On the other hand, they are working on technology which directly affects the way people think and act. This implies that altogether *different types of engineers* are required, engineers who can be distinguished as to (i) disciplinary background: electrical engineering, chemical technology, technical medicine, computer science, architecture or business administration; (ii) the nature of their work: research or design; and (iii) their orientation: specialists or generalists. Specialists are often driven by the challenges and new opportunities provided by technology. It fascinates them and they wish to participate in developing and improving it. Generalists are often motivated by the societal issues that can be solved by means of technology. But these are, of course, stereotypes. It is not unusual to hear someone say, ‘I’m a bit of a nerd, but for a good cause’, something which expresses both a fascination for technology as well as social engagement. Both generalists and specialists should be able to function at the boundaries of various disciplines. These boundaries can vary widely. Interaction with physicists, for instance, is completely different from interaction with psychologists or doctors.

There are also other developments that can be termed robust in the sense that they are compatible with a number of possible future scenarios. *Internationalization* is a prime example, one that is in fact inevitable. In the past fifty years, the world's economy has witnessed a strong shift to Asia, with China now having reached the level of the United States and the European Union. As a result, companies will have to operate on an increasingly international scale and all engineers without exception will have to be educated for the international market. This conclusion is unrelated to the question whether TU/e should, in the future, focus mainly on the ecosystem of international high-tech industries in the Eindhoven region (Brainport), or whether TU/e should primarily be developing itself as part of an international network of universities (a 'global university of technology'). In either scenario, internationalization plays a key role. There is yet another reason why internationalization is an absolute must: if TU/e aspires to excellence in education and research, it necessarily follows that the world, not just the Netherlands, is its arena.

A university that presents itself as a world player is nevertheless embedded in a local environment and will want to contribute actively to its prosperity and well-being. TU/e is part of the Eindhoven region, a unique area with a high concentration of international high-tech industries – hence the name Brainport. A significant number of TU/e students come from this area and a major share of its alumni work for companies located in the region. Having good cooperative relations with the region, which by virtue of its international orientation provides yet another window on the world, is therefore a requirement for TU/e in determining the future of education and research.

Another robust development is a *greater diversity* of students. This means a student body comprised of several types of students interested in science and technology,[4] a larger share of women, more nationalities, more students from immigrant communities, etc. This diversity is needed to ensure a greater intake so that sufficient numbers of people can be trained in technology. But it is also necessary because the market requires engineers with widely varying profiles, as has been illustrated above. We are not just concerned with one type of engineer of the future. There are several. Finally, diversity is needed to prepare students for an international career in which cultural differences may play a major role.

What applies to students also applies to TU/e staff: greater diversity is also necessary and desirable here. Staff members act as role models for the students, especially where women in technology are concerned. Increasing the diversity of the staff population, however, is something that cannot be accomplished in the short term. TU/e will only be able to introduce changes by implementing a firm and consistent policy over a number of years.

Another development that will not easily be reversed relates to government funding of higher education. We have been witnessing a downward trend for years. In the first decade of this century, the government's contribution for each student dropped from €18,800 to €14,100, while the number of students increased by 46 percent.[5] The introduction of a new student loans system instead of grants in the Netherlands is part of the picture. This downward trend is entirely unsatisfactory given the vision that is communicated by that same government, namely that the competitive power and hence the future of the Dutch economy lies in knowledge-intensive products and services. It puts great pressure on the educational system at Dutch universities, as degree programs have to be offered to an increasing number of students per staff member that at the same time belong to the best programs internationally. This is all the more acute because, as will be argued below, small-scale education is a vital element of good academic teaching practice.

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4 *Youngworks: **Beta Mentalities**. See: http://www.betamentality.nl//docs/Publicaties/betamentality-2011-2016.pdf. The term 'science and technology' refers to science, technology, engineering and mathematics.*

5 *For more information see: http://www.vsnu.nl/f_c_prijs_per_student.html.*

TU/e core values

"the pursuit of the highest possible quality"

4

In addition to these (and still other) more predictable future developments, there are also trends that are hardly foreseeable and render speculation about them futile. When it comes to these unpredictable trends, TU/e must always be guided by its stated mission and its core values as a higher education and research institution. A core value of prime importance is the pursuit of the *highest possible quality*. Quality is a value concept which expresses how good something is in light of relevant indicators. If there is one place within society where the more or less uncompromising pursuit of high quality should be possible, it is the university. It is the place where there should be the academic freedom to produce the most economical car in the world, the best heart valve for children or solar cells with the highest efficiency. In all other sectors, after all, pragmatic considerations, such as feasibility in the market, limited time and capacity etc., will always prevail and such factors can compromise the quality of a product.

At a university of technology, the pursuit of the highest possible quality is reinforced by the basic attitude of the engineering sciences, which is one of 'Let's make things better'. Progress is an essential part of the engineering profession, and it is also an attitude which is instilled in students in their education. Engineers strive to make products or develop processes with new or improved functionality, which are more sustainable or less reliant on scarce resources, or are faster, lighter, smaller and less expensive than existing products or processes. Moore's law, which states that in the history of computing hardware the number of transistors on integrated circuits doubles every two years, is a good illustration of this.

To say that the pursuit of the highest possible quality is a core TU/e value is at the same time to observe that quality assessments are notoriously difficult. Quality is not something that can simply be established or measured. In Einstein's words, 'Not everything that counts can be counted, and not everything that can be counted counts'. Quality assessments are all-things-considered judgments, in which a number of indicators play a role. Some of them can be measured and others cannot, while some are generic and others discipline-specific.[6]

In addition to the pursuit of the highest possible quality, TU/e also upholds core values resulting from its mission as an institution for *academic* education and research –

reliability, openness, independence, intellectual honesty and societal responsibility[7] – core values which evolve from TU/e's mission as a *technological university* – innovative, enterprising, contributing towards society – and core values which follow from TU/e's function as a *societal organization*–respect, integrity, transparency, commitment.

Not only staff members but also students must abide by these values. Students are regarded as researchers and designers in the making. In the bachelor's degree program, the master's degree program and the PhD/PDEng program, students go through several phases during which they familiarize themselves with the principles of academic integrity and learn to act on them. They are furthermore challenged to be innovative and enterprising and to make their mark on society, and they also become acquainted with the importance of values such as respect and transparency within a teamwork setting.

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6 *See also the **Quality Assessment in the Design & Engineering Disciplines** report by the Royal Netherlands Academy of Arts and Sciences (KNAW), Amsterdam 2010.*

7 *See also TU/e **Code of Scientific Conduct** (2013) and the **Nederlandse Gedragscode Wetenschapsbeoefening** (VSNU 2005/2012).*

Excellence as a core value of education

“the connection between education and research will also remain vital in the future”

5

In education, the pursuit of the highest possible quality translates into the pursuit of excellence. This is true both for students – who are encouraged to bring out the best in themselves in the course of their studies – as well as for teaching staff, for whom teaching is a core task. It is in the encounter between the two that the learning process takes place and students are molded.

There are two sides to educational excellence: form and content. Excellence of didactic form is achieved by tailoring teaching methods to the objectives of the learning process, to the content that is being taught and to the type of student being taught. Excellence of content is reached by linking education to research. Having a strong connection between the two, especially in the master's degree program, challenges the students to bring out the best in themselves and shows them how to practice the engineering profession at the highest level in interaction with their teachers.

Top-class science is often compared to top-class sport. There is a lot of truth in this metaphor, in particular where it concerns the effort and attitude that is required to reach the top. Training is an essential aspect in this sense, and this is particularly true for two mental abilities which are of fundamental importance in the sciences: (i) the ability to move from the concrete instance to the general insight (abstraction) and vice versa from the general insight to the concrete instance (concretization); and (ii) the ability to move from the overall problem or system to its constituent parts (analysis) and vice versa from the constituent parts of a problem or system to the whole (synthesis). These two abilities will have to be exercised time and again throughout the study program, and their complexity will gradually have to increase. Excelling in these mental skills, something which is, in the technological sciences, often supported by schematic drawings or formal representations, is a necessary, though in itself not a sufficient, condition for being able to practice 'top-class sport' as an engineer.

Societal responsibility

"a special responsibility for the Brainport region"

6

TU/e is aware that it has a special societal role to play as a university of technology. This responsibility has to do with the enormous impact of technology on society[8] and the major role engineers have in helping to solve the enormous problems and challenges facing the world. These include problems in the fields of sustainability and energy, terrorism and conflict management, health and population ageing, water and food supplies, financial stability and employment. There is no ‘technological fix’ for any of these societal issues, but technology will be able to make a significant contribution towards providing solutions for them.[9-10] In 2013 the US National Academy of Engineering formulated a number of ‘Grand Challenges for Engineering’ on the basis of these ‘Grand Challenges for Society’:[11]

Make solar energy economical	Provide energy from fusion
Develop carbon sequestration methods	Manage the nitrogen cycle
Provide access to clean water	Restore and improve urban infrastructure
Advance health informatics	Engineer better medicines
Reverse-engineer the brain	Prevent nuclear terror
Secure cyberspace	Enhance virtual reality
Advance personalized learning	Engineer the tools of scientific discovery

TU/e wishes to make a substantial contribution to a number of these Grand Challenges by means of its strategic areas. These are thematic fields of research for the medium term (5-10 years), which are based on long-term TU/e research strengths. In 2010, the strategic areas were defined as health, energy and smart mobility. They are interconnected, for instance through the generic theme of sustainability. These strategic areas are characterized by the coupling of fundamental research to major societal issues, resulting in mission-oriented fundamental research. In education, these three areas will come to play a decisive role as a source of ‘real life problems’ which students can work on, for instance in the context of their graduation project or an honors project. But they also serve as a source of inspiration to students who are primarily motivated by technology’s major societal impact and potential.

The Grand Challenges are indeed grand. They underscore the societal need for engineering science of the highest caliber and for TU/e to educate engineers that are among the best in their profession. Without this pursuit of excellence, it is virtually impossible to meet these grand challenges.

TU/e also bears a special societal responsibility with respect to the region in which it is embedded. The Eindhoven Brainport region is one of the Netherlands' three economic pillars. It is also its industrial heart, hosting as it does numerous international high-tech companies. A major share of the Dutch GNP and a large part of Dutch export are generated here. It is also the region that surpasses all others when it comes to privately funded R&D. TU/e wishes to contribute to the prosperity, well-being and employment opportunities of this region by educating the engineers the region needs and by carrying out research that stimulates innovation in the region, in other words, by being the university 'where innovation starts'.

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8 *History shows that this impact can be positive as well as negative.*

9 *See, for instance, Van Santen, Khoe and Vermeer,* ***Technology That Will Change the World****, Oxford UP 2010.*

10 *The EU's Horizon 2020 Framework for Research & Innovation addresses a number of these major societal challenges. See http://ec.europa.eu/research/horizon2020/index_en.cfm?pg=better-society.*

11 *See e.g.: http://www.engineeringchallenges.org/.*

Education in 2030

“learning how to learn must become a major learning objective of education at TU/e”

7

There is a lot of speculation nowadays about the future of education, in particular about the role of ICT. Massive Online Open Courses (MOOCs) and other forms of online education will replace conventional education and open the way for higher education that is less expensive and also accessible to a greater number of students. New media will take the place of traditional teacher-student interaction, etc. It is good, however, to qualify these great expectations. The Internet has indeed caused a revolution in the amount and accessibility of available information. Never before has it been so easy to access so much information. The question is, however, whether it has also fundamentally changed or will change the way people learn. Learning processes are embedded in people's mental make-up. These cognitive structures of the brain change on a different time scale than ICT. In other words, Darwinian evolution does not conform to Moore's law. In twenty years time, therefore, students' learning processes will probably not be essentially different from what they were twenty years ago. Naturally, the character of certain cognitive skills will change, such as the way information is retrieved. But this does not have any bearing, or bears to a far lesser degree, on the growth of understanding and insight: the ability to learn to see connections, to learn how to work out underlying mechanisms, or to learn how to make new things on the basis of that which already exists. This means that personal interaction and the exchange of knowledge between teachers and students are and will continue to be what academic education is all about. The word 'university' is derived from the Latin *universitas magistrorum et scholarium,* referring to a community of educators, researchers and students. This is what it is essentially about. The viewpoint is aptly expressed by Samuel Allen, the chairman of the recently established Taskforce 2030 at MIT:

'MIT will remain a campus-based university, and the value of maintaining it as such lies primarily in the degree to which its students learn from one another. Collaboration among students and inter-action with faculty, whether they take place in formal or informal settings, are distinguishing qualities of the academics, research and community activities that take place at a campus-based university. [...] No doubt, by 2030, technology-enhanced tools that significantly enhance learning will be commonplace in MIT's academic offerings. Let's assume that using these tools eliminates a significant fraction of 'chalk-and-talk' lecturing. This would free up faculty time that can be devoted to other activities that will change our day-to-day activities as educators. [...] More faculty will need to participate in mentoring, and deeper and enduring mentor/mentee relationships will be necessary. Faculty engagement with students will need to extend beyond the academic and research spheres and into the community sphere'.[12]

What is true for MIT is probably also true for TU/e. In the future, it will become more important to connect formal to informal learning and to link learning to living in an academic community. Such a community, however, will have to be small-scale in order to be effective. Here lies a major challenge for TU/e. With growing numbers of students, courses will have to be organized in such a way so as to allow them to remain small-scale and not inhibit the master-apprentice relationship. It goes without saying that ICT must be optimally deployed in this learning environment. Online education is eminently suited for transferring knowledge to large groups. In this way teaching capacity can be freed up to continue teaching small groups of students.

TU/e wants to educate new generations of academic engineers who are able to make significant contributions to society some ten, twenty or forty years into the future. One thing is certain: the society of the future will differ from ours and will also make other demands on engineers. The engineering profession will change and students must as a result be educated in different ways. Amongst other things, the above-mentioned Grand Challenges reveal the enormous complexity of the issues which engineers will be facing in the future. These challenges are essentially multi-disciplinary in nature. Solving them requires input from the engineering sciences and the natural sciences, but also from the social sciences and the humanities. This is also true for the development already referred to above, namely that technology is playing an increasing role in the private lives of people. For TU/e this means that educational bridges must be built between disciplines, both technological and non-technological.[13] There are more reasons to take this step. Much innovation takes place at the interface between disciplines and students must learn to seek and embrace the creative tension arising from multidisciplinary contacts. Once they have embarked on their professional careers, they will always be working in multidisciplinary teams – this, too, is a skill that must be developed.

A word of caution is in place when it comes to multidisciplinarity, however. There is the risk that a multidisciplinary approach will turn out students who are 'Jacks of all trades, masters of none'. Such an outcome conflicts with the view that excellence must be the focus of education. There are various solutions to this problem, depending on the question whether the technological domain itself is primarily monodisciplinary (chemistry, physics) or multidisciplinary (biomedical technology, building and architecture). One solution for those taking a multidisciplinary BSc may be later specialization in a single discipline in their MSc studies.

In recent years, there have been many studies into long-term developments in higher education by the OECD and the EU amongst others. Simplifying somewhat, three trends can generally be distinguished on the basis of these studies:

- A greater influence on education of a changing society;
- A much stronger focus on *learning how to learn* and on the individual demands of students; related to this is a greater tutoring role for teaching staff;
- A greater role for ICT in education.

The second trend in particular merits attention. Students will have to be prepared for a career which necessarily involves lifelong learning, something which must be acquired as a basic learning attitude. That attitude is an academic prerequisite (because of the numerous and rapid developments taking place in researchers' areas of expertise) and a societal requirement (due to increased worker mobility and the growing role of technology in society). The significance of the university degree therefore shifts from that of indicating the end of the learning process to that of indicating a basic qualification for a career marked by lifelong learning. *Learning how to learn*, therefore, must become a major learning objective of education at TU/e.

In the transition towards a future educational system it is important not to forget the strengths of current educational practices and to incorporate them in the new system. Small-scale education is one of them. Another one is design-based education (OGO) as developed at TU/e. This type of education significantly contributes to the preferred profile of TU/e-trained engineers.[14] A third one is the practice-based education in workshops and laboratories that is characteristic of engineering, a form of education in which conceptual as well as practical skills are taught.

Below, the consequences of the three above-mentioned trends for students, teaching staff and TU/e will be discussed separately.

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12 *Allen, S. M. (2011),* ***MIT 2030: The Education Part,*** *MIT Faculty Newsletter, 24 (2), November 2011.*

13 *At TU/e's Bachelor College this is done, among other things, by offering students interdisciplinary or multidisciplinary elective course packages that transcend faculties. In addition, they have to choose a USE course sequence. USE is an acronym for User, Society and Enterprise, which involves training in the social sciences, the humanities and management sciences in relation to technology.*

14 *See* ***Evaluatie van de Implementatie van OntwerpGericht Onderwijs*** *(OGO), ACQA Project group TU/e, June 2013.*

Consequences for students

“students become in control of their own study program to a significant degree”

8

There are a number of fundamental changes in store for students. The societal and functional need for a greater diversity of engineers and the progressive trend among students to construct their own education implies that it is no longer sufficient to offer a limited number of preprogrammed options as degree programs. It is not the educational institutions but the students who will have to determine, in light of their own interests, intrinsic motivation and plans for the future, which engineering profiles are important for them. This was one of the insights offered by TU/e's taskforce for redesigning bachelor courses in 2011.[15] It implies that education at TU/e must be organized in such a way so as to allow students the opportunity to develop, on top of a broad and solid knowledge basis, their own profiles and engineering specialties, first in the bachelor program, then in the master program.[16]

This reversal from supply-driven to demand-driven education enables students to be in control of their own study program to a significant degree. It also makes great demands on students, certainly at the beginning of the bachelor's degree program when the big leap has to be made from secondary to higher education. Students can no longer be passive consumers of knowledge in higher education. They must actively work out their own study program. They will have to be extremely well prepared to be able to make these choices. The reversal from supply to demand therefore also requires extra input from teaching staff: they must come to play an active role in the personal supervision of students and support them in their individual learning process and profile development.

The learning process will no longer be uniformly structured over time for all students. There will be greater differentiation in place and time, depending on the students' preferences. This is also more in line with the foreseeable greater integration of education and career practice in future. Education does not end once the master's degree has been obtained. This development dovetails with the previously described changes in the teaching process at TU/e, whereby students must learn to develop their own academic profile and shape their learning process themselves. It is a skill which will be a crucial asset in careers that depend on lifelong learning.

ICT will play a major supportive role in these learning processes. More and more content will become available via the web. Students will combine physical presence in lectures, instructions and practical training with web-based self-tuition. Assuming that some of the 'Grand Challenges in Science Education' can be overcome, experiments may partly be followed or carried out at a distance and online.[17] Distance learning, however, has its limitations, as has been demonstrated by various studies. Not every 'learning outcome' is equally well suited to this purpose. The future, therefore, lies in 'blended learning', where the Eindhoven blend includes small-scale education and design-based education. Many students consider physical presence during tuition and real interaction with teachers in a small-scale setting to be an essential aspect of their education.[18]

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15 ***Toekomstbestendig en Studentgericht Bacheloronderwijs,*** *final report of TU/e Taskforce Redesign Bachelor Curriculum and Standpunt College van Bestuur, Eindhoven May 2011.*

16 *In TU/e's Bachelor College the development of this broad knowledge base starts with basic subjects that students of all major programs must take. The wide range of 45 EC optional courses allows them to develop their own profile.*

17 *Special issue 'Grand Challenges in Science Education',* ***Science****, Vol. 340 (2013), Issue 6130, 237-396.*

18 *See also Gorissen, P. (2013),* ***Facilitating the Use of Recorded Lectures: Analyzing Students' Interactions to Understand their Navigational Needs,*** *doctoral dissertation TU/e, Eindhoven (Eindhoven School of Education).*

Consequences for teaching staff

"a greater diversity in the student population and more tailor-made education"

9

TU/e staff, especially teaching staff, from assistant to full professor, make up the intellectual capital of the university. They are responsible for training generation after generation of students to assume important positions in society. They make the difference: when they fail as educators, opportunities for society and the economy are lost. When they succeed, the result is the creation of opportunities and solutions previously held to be impossible. Any university should therefore cherish its teaching staff.

The task of teaching staff will certainly not become simpler in the future. There will be greater diversity in the student population, something already noted above. Teachers will have to be responsive to this and deliver more 'tailor-made' education. Students will have to be tutored as part of their individual learning process, have their intellectual curiosity stimulated and be supported in making choices and developing their own profiles. A personalized approach also requires greater variety of teaching methods, so as to accommodate differences in background, level, motivation and learning style. This is especially true for interdisciplinary and multidisciplinary education, which is already complex by nature.[19]

In addition, there will be a shift in education from specific content to graduates' output qualifications: the learning outcomes.[20] This means that teachers will have to focus on developing and assessing learning outcomes more than is presently the case. This shift has to do with the changing demands of society on graduates,[21] with the internationalization of education and the desire for greater mobility between educational institutions within the EU, as well as with the rapid developments within disciplines, as a result of which the ability and preparedness for lifelong learning (as distinct from specific content) becomes ever more important. With regard to the latter, TU/e will also have to develop assessments for learning in addition to the present assessments of learning.[22]

ICT will, here too, have to fulfill a major supportive role in various didactic functions. Teachers will make increasing use of software, for instance to prepare adaptive assessments or simulations.

The use of video material in education will expand and free up more time for the vital small-scale interaction between teachers and students. ICT also allows providing tuition together with teachers anywhere in the world. With the greater role of ICT in education, the key question must remain: *what is the didactic philosophy guiding the use of ICT?* Many case studies have shown that simply transferring teaching materials from an analogue to a digital learning environment is not a recipe for success.

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19 *Czerniak, C. M. (2007), 'Interdisciplinary Science Teaching', in S. K. Abell & N. G. Lederman (Eds.),* ***Handbook of Research on Science Education****, 537-559, Mahwah, NJ: Lawrence Erlbaum Associates.*

20 *The notion of 'competence', which is often referred to in relation to learning outcomes, is one which is not popular across the board. It is often associated with developments in secondary and vocational education that are regarded as disastrous: 'content-free competence learning' whereby the knowledge component of education is neglected in favor of general competences such as the ability to communicate and cooperate. The term 'learning outcome' is less charged in this respect than the term 'competence', as it is meant to express a combination of knowledge, skills and attitude. The notion of competence used in TU/e's publication* ***Criteria for Academic Bachelor and Master Curricula*** *and in the related Eindhoven quality assurance system ACQA is similar to learning outcome.*

21 *A number of these above-mentioned learning outcomes are also referred to in popular literature as '21st century skills'. See, for instance: http://www.21stcenturyskills.nl/achtergrondinformatie/.*

22 *Schleicher, A. (Ed.) (2012),* ***Preparing Teachers and Developing School Leaders for the 21st Century: Lessons from Around the World,*** *OECD.*

Consequences for TU/e

"excellent education demands an appropriate ICT infrastructure "

10

The developments that have been described above also involve fundamental changes on an institutional level. Some of these relate to the short term and have been partly integrated in the Bachelor College and Graduate School, others will come into effect in the medium and longer term and will require further adjustments of the educational system.

Education that is driven by student demand means that degree programs must necessarily become more flexible. TU/e's Bachelor College and Graduate School offer a structure for this process. At the same time, there can be no question of an 'anything goes' approach. TU/e must be able to vouchsafe the quality of the individual degree programs of students and ensure that the learning outcomes mentioned above will actually be met. Flexibility may also imply that TU/e will be offering its students and alumni specific modules or learning pathways at other than regular times, for instance in the evenings or weekends. This may also be necessary in order to compensate for the restrictions of the timetable and the availability of teaching space. Although there are, of course, also practical limits, it is obvious that greater flexibility is of the essence.

There can be no excellent education without excellently trained teaching staff. In light of the increasingly complex tasks of teachers, their continuous professional development is an absolute necessity. This will have to become a standard component of the HRM policy at TU/e, a component that transcends the basic university teaching qualification. Lifelong learning is also necessary for teaching staff. Separate trajectories for staff members specializing in education are therefore inevitable. For these staff members, education will also often be an area of research, for instance when developing evidence-based best practices.

Excellent education does not exist without an appropriate educational infrastructure. Here, too, TU/e is confronted with major challenges, in particular when it comes to working out the 'compact campus' plans as formulated in Campus 2020. The available teaching rooms must be adjusted to TU/e's educational vision and future student population in terms of number, range and facilities. Student housing, too, is of great importance, especially in light of increasing internationalization. Finally, the ICT infrastructure is also of crucial importance, as has been argued above in several places. Infrastructure will have to develop in conjunction with the future role of ICT in the bachelor and master programmes, especially in education for large groups. It is expected that MOOCs, selectively applied to specific strengths of TU/e, will become an important aspect of education for professionals in the context of lifelong learning.

It is to be expected that in the future, TU/e will increasingly be held accountable for the use of public funds. A good example of this are the current performance agreements that have been concluded with the Ministry of Education, Culture and Science. TU/e is expected to be accountable for the quality of education, but also for the efficiency with which public funds are deployed (for instance the graduation success rate of the degree programs). The same applies to institutional accreditation, in which the quality assurance process in education is evaluated in detail, and TU/e must be able to demonstrate that all relevant aspects of quality assurance are under control. Thanks to the increase of available information and storage capacity, it is assumed that in the future, quality assurance will increasingly be supported by means of ICT, for instance through data mining.

The growing importance of lifelong learning as a result of the numerous changes in society and the rapid developments in science and technology has consequences for the degree programs offered at TU/e in the medium term. It will substantially change the student population, while the supply of educational options will have to be geared more to alumni and other professionals wishing to continue training in the subjects TU/e excels in. Working and learning will alternate with each other or mixed forms will evolve. In the near future, TU/e will have to formulate an answer to the question as to which position it wishes to occupy in the post-graduate training market. Learning trajectories in the context of lifelong learning can also be offered – in part – by companies and other organizations. This integration of working and learning increases the need for ways of mapping and, where necessary, certifying informal knowledge and learning outcomes obtained in practice (see also the MIT 2030 vision).

These developments will also lead to greater involvement of companies and societal organizations in academic education. Over the years, TU/e has set up a strong research collaboration network with technological companies in the Brainport region, for instance through PhD and PDEng projects. This tradition of collaboration is one of the strengths of TU/e, but it is a strength which is not yet used to full potential in the educational programs. The question is in what way these companies will be able to play a more meaningful role in the degree programs offered at TU/e than is currently the case. Their role can vary from coupling teaching material to real-life examples to greater involvement in internships and graduation projects in the bachelor's and master's degree programs. The main contribution these companies will be able to make, however, is probably in the field of future education in a lifelong learning context. It is certainly possible that mixed trajectories of working and learning will evolve, with companies bearing a shared responsibility for components of degree programs carried out in practice, including their assessment.

For technological companies, highly educated staff comprises the short-term capital, while students represent long term capital. The involvement of companies in the degree programs offered at TU/e is therefore a matter of well-understood self-interest. This involvement is also of great importance for the university, in view of its mission with respect to education and valorization. It is often forgotten that the most important valorization of TU/e knowledge consists in the approximately 1,000 academic engineers who are delivered to society and so also to the business community on an annual basis.

Summary of main points

“small-scale education and master-apprentice interaction as key components of academic education”

11

A vision for the future is a compass, pointing out the direction TU/e wants to take in the medium and longer term. A university, however, is not a speedboat that can swiftly change course – it is rather more like a tanker. Only by carrying out a consistent and long-term policy is it possible for an organization of 3,000 staff members and researchers and 7,500 students to reach its intended destination. That spot on the horizon is defined by the university's mission, the values it espouses and a number of medium- and long-term developments outside and inside the university.

TU/e's educational mission is to educate academic engineers who are future proof and who are able to make innovative contributions to society in the course of their entire four-decade career.
These engineers will be guided in their thinking and actions by a number of core values which are also characteristic of TU/e's staff members. The pursuit of excellence in education and research is a value which, more than all others, defines what TU/e is about or should be about.

Among the medium- and long-term developments that are probably robust in the light of a range of possible futures are: the increasing pervasiveness of technology in people's personal lives, the continuing internationalization of society and education, a greater diversity of students and staff, a further drop in central government funding of higher education and increasing demands that universities account for the use of these means.

The connection between education and research will also remain vital in the future. But there are important changes underway: demand-driven education on the part of students developing their own academic profile, a greater tutoring role for teaching staff, the growing importance of interdisciplinarity and multidisciplinarity (including the social sciences and the humanities), a greater role for learning outcomes in education and quality assurance, a stronger emphasis on lifelong learning, greater involvement of companies and societal organizations in education, the continuing professional development of teaching staff and a greater role for ICT and online education.

As for the latter, the university of the future will not consist of a server farm that supports online courses that can be attended by students all over the world. To an important degree, the learning process takes place in the encounter between students and teachers. Some elements can be provided online, others cannot. The future, therefore, lies in blended learning, with both digital and analogue elements each having their specific didactic roles to play. This is also true for small-scale education, which is where the real interaction between students and teachers takes place. At the same time it poses a great challenge to TU/e: how is it possible to realize small-scale education in the face of growing student numbers and reduced financial support from the government per student?

A vision for the future is a tool that helps making necessary choices. Recently, TU/e decided to establish a Bachelor College and a Graduate School, in which a number of the elements described above have been incorporated. At the same time, it is clear that renewing the educational system does not end here, as anyone working in higher education is all too aware. In this process of renewal, it is necessary to keep a clear view of major and minor issues, of long-term and short-term developments, of means and objectives. The focus must be on the long-term objective, which must guide us in the choices we are making here and now. As Michelangelo so aptly put it, 'It is necessary to keep one's compass in one's eyes and not in the hand, for the hands execute, but the eye judges.'