

# ENGINEERING EDUCATION IN A RAPIDLY CHANGING WORLD

Rethinking the Mission and Vision  
on Engineering Education at TU Delft







# Colophon

---

Title: Engineering Education in the Rapidly Changing World

Subtitle: Rethinking the Mission and Vision on Engineering Education at TU Delft

Author: Aldert Kamp

ISBN 978-94-6186-403-1

Delft, October 2014



Delft University of Technology  
Faculty of Aerospace Engineering  
Kluyverweg 1  
2629 HS Delft  
The Netherlands

tel: (+31) 15 278 5172

e-mail: [a.kamp@tudelft.nl](mailto:a.kamp@tudelft.nl)



This work is licensed under a Creative Commons Attribution-NonCommercial 3.0 Licence



*Mega cities and future transportation.*



## Foreword

---

“TU Delft’s mission is to make a significant contribution towards a sustainable society for the twenty-first century by conducting ground-breaking scientific and technological research which is acknowledged as world-class, by training scientists and engineers with a genuine commitment to society and by helping to translate knowledge into technological innovations and activity with both economic and social value.”

“To be the best Aerospace Engineering faculty in the world, inspiring and educating students, staff and society through modern education techniques and performing ambitious research of the highest quality for the future of aerospace.”

With these two mission statements of TU Delft and the Faculty of Aerospace Engineering respectively I was challenged in 2010 to establish a vision for education in my faculty during the “Educational Leadership” training at the Centre of Excellence in University Teaching of Utrecht University. I soon found out that TU Delft’s vision on education is scattered over various documents and emphasises the “how”, both in its pedagogical approach and orientation on problem solving skills, and not so much on the “what” is needed, let alone the “why”. One of TU Delft’s first documents on its vision for education “Focus op Onderwijs” (2003) was about increasing influx, higher efficiency, the minors and honours programmes, and active teaching. The chapter on education in the strategic document “TU Delft Roadmap 2020” (2010) focused on societal relevance, selection, differentiation, profiling, excellence and international orientation. The most recent document on a vision in education “Charting a Course for Study Success” (2011) was about technocratic curriculum changes like course size, modularity and formative assessments, with the aim of improving study success.

Important steps were made by the Directors of Education in two dedicated meetings about Vision on Engineering Education in May 2013 and March 2014. In the first meeting quite some time was spent on navel-gazing, emphasising the value of deep mono-disciplinary knowledge, student ambition, excellence programmes, rigour of assessment, the link between research and education, and the need for excellent facilities. Open minds addressed the relation with the world of work, the impact of the global economy, the shelf life of knowledge, the need for innovation and the interdisciplinary mind-set, global interconnectedness and the use of open standards. These are the factors that describe the rapidly changing world in which we live and in which we educate tomorrow's engineers that may be a different breed than we have been educating over the past 50 years. These factors set the scene for the "why" and "what" of our future education.

My interest in the changing world and its impact on engineering education was kindled in 2013 after a visit from David Goldberg of iFoundry to my office, talking about "The 7 Missing Basics of Engineering", and a keynote speech at the CDIO Annual Meeting in 2013 at MIT by Tony Wagner of Harvard's Innovation Lab about "The Seven Survival Skills", which, by the way, have nothing to do with the seven missing basics of Goldberg. At CDIO conferences I learnt that pioneering schools in Asia such as the Singapore University of Technology and Design (SUTD), the Renaissance Engineering Programme of Nanyang Technological University (NTU), the Zhejiang University (ZJU) in China, the Pontificia Universidad Católica de Chile (PUC) in South America, and the Skolkovo Institute of Science and Technology in Russia all develop or innovate their curricula at an incredible pace. I realised that the engineering and academic worlds change rapidly, but that many engineering programmes seem hardly aware of the impact, or show a dangerous sense of complacency.

With this document I provide a lens through which the reader can reflect on the future world of work of the engineer and its potential impact on engineering education. The document does not consider what will be the jobs of the future but rather looks at the future work skills, proficiencies and capabilities that will be required across different jobs and work settings. It is especially about the "why" and the "what" of our education. I will start with a conceptual mission statement for engineering education at TU Delft in the 21<sup>st</sup> century, in order to have a beacon on the horizon for my investigation. In line with this mission statement I have established a number of vision statements for the attributes that our engineering students will have to acquire for a successful career in the future world of work. They are the attributes that are most frequently addressed in the literature, conferences and workshops about innovative (engineering) education, societal challenges and developments in relation to engineering sciences. They are highly relevant for the students whom

we educate in the Master's and prepare in the Bachelor's with the foundational capabilities. The vision statements are based on information from sources that I have used to generate ideas and "read around" the topic (listed in the bibliography): the literature, personal notes of presentations, roundtable sessions, panel discussions and workshops with universities and global players in business and development, mainly during European conferences and workshops on engineering education and skills.

Since Boeing issued the list of "Desired Attributes of an Engineer" in the early nineties, changing higher education in engineering has been the subject of an on-going discussion in the US and Western Europe among industries and engineering universities. But achieving the change has become a serious barrier. The concerns grow that perpetuation of the old paradigm by the universities will cause future engineering graduates to become employees who will have difficulty dealing with the pressing demands of the fast-paced global market place, and may even end up as a commodity. It's the joint responsibility of the scientific and supporting staff and the student body to become aware of the rapidly changing world and make conscious choices concerning if and how we want to reflect the major shifts in engineering attributes in the learning outcomes of our future programmes. I hope this document will inspire conversations about future proofing the Bachelor, Master, Minor and Excellence programmes in the faculty, as well as at the university level, in consultation with stakeholders in the job market, and that it will set the scene for the Think Tank at the 3TU Centre of Engineering Education, whose aim is to investigate and develop scenarios of future campus education at TU Delft.



**Aldert Kamp, Delft, October 2014**

*Director of Education TU Delft Faculty Aerospace Engineering  
Council member of the Worldwide CDIO Initiative  
Leader 3TU Centre for Engineering Education*

<sup>1</sup> European Space Agency (ESA), Airbus Industries, ASML, Advisory Council Aerospace (TUD), Boeing, General Electric (GE), German Aerospace Centre (DLR), National Aerospace Laboratory (NLR), Philips, Rolls Royce, Royal Netherlands Airforce, Safran Group (France).





# Contents

---

Foreword	3
Contents	7
Mission Statement for Engineering Education TU Delft	8
Engineering education at a crossroads	9
Enabling the development of more than just cool technologies	15
1 Rigour of Engineering	16
2 Critical Thinking and Unstructured Problem Solving	18
3 Interdisciplinary and Systems Thinking	18
4 Imagination, Creativity, Initiative	21
5 Communication and Collaboration	22
6 A Global Mind-Set: Diversity and Mobility	24
7 Ambitious study culture: Student Engagement and Professional Learning Community	26
8 Employability and Lifelong Learning	30
Conclusion	33
Bibliography	35

# Mission Statement for Engineering Education TU Delft

TU Delft's Mission Statement "To make a significant contribution towards a sustainable society for the twenty-first century by conducting ground-breaking scientific and technological research which is acknowledged as world-class, by training scientists and engineers with a genuine commitment to society and by helping to translate knowledge into technological innovations and activity with both economic and social value" addresses societal relevance, the 21st century, a commitment to society, and translating knowledge into solutions with value.

Due to the integrated statements for research, education and valorisation, in one statement, it does not stick in the mind, nor does it reflect TU Delft's slogan "Delft Engineers: Making ideas work".

For orientation in a changing world and its potential impact on engineering education, an education-oriented Mission Statement is needed. It will serve as a beacon that will help to identify the key attributes of tomorrow's Delft graduates, and guide the development of vision statements for these attributes. The following formulation of a Mission Statement for TU Delft's engineering education is in line with the above TU Delft Mission Statement, refers to TU Delft's slogan, and will stick in the minds of students and staff.

*"The Delft Engineer has the ability to help solve the societal and engineering challenges of the 21st century through creative workable solutions"*

*(In Dutch: De Delftse ingenieur wordt opgeleid om met creatieve haalbare oplossingen te komen voor de maatschappelijke en engineering vraagstukken van de 21<sup>e</sup> eeuw).*



# Engineering education at a crossroads

---

Between now and 2050 the world population will increase from 6 to more than 9 billion. Eight of the nine billion will live in the less developed countries of Africa, Asia, and Latin America, whose economic growths are expected to be only slightly less than in the more developed countries. This presents future society with enormous challenges on many fronts, such as energy, infrastructures in urban settings, mass migrations, mobility, climate, healthcare for an aging population, social security and safety. To understand and solve these challenges, incremental solutions will not always be enough. In the coming decennia leaps in scientific discovery and innovations will be necessary in social, political, economic and technological fields. They will result in a transformation of life, business and global economy as we know it today. Technology, the domain of engineers and engineering scientists, will be an essential component in making such innovations possible. In 2050 today's generation of students will be somewhere in the middle of their career and operating as an expert, a change agent, or an innovator. They should possess the capabilities and a mind-set beyond technical expertise, both in their profession and in their classroom. Many of today's engineering tasks (and curricula in higher education in engineering) still focus on typical 20th-century how-to-do-it activities, associated with product and service design, manufacturing and support. They made sense in the 20th century, but tomorrow's engineers will be called upon to perform an increasing amount of what-to-do functions, and

*"Nowadays we attempt to educate 21st-century engineers with a 20th-century curriculum taught in a 19th-century institution."*

*Grasso and Burkins (2010)*

will engage with experts from multiple fields. The new breed of engineers will not only be comprehensive problem solvers, but also problem definers, leading multidisciplinary teams in setting agendas and fostering innovation, which requires an entrepreneurial attitude.

Engineering education must be regarded as a strategic foundational element, alongside technical research, in building innovation capacity. Many of the societal and engineering challenges are that complex and multidimensional that they cannot be unlocked with the old-fashioned key of sciences

and technology alone, but also

need socio-economic capabilities.

Engineering is the social practice of conceiving, designing, implementing, producing and sustaining complex technological products, processes or systems. The complexity is often caused by the behaviour of the system development that changes with time that cannot be predicted in advance from its constitutive parts. This is especially true when human decisions play a key role in solving the problem.

Solving complex systems requires a solid foundation in mathematics

and the natural sciences, and an understanding of human nature. Therefore, the skills of the engineer of tomorrow must extend over an array of fields.

*“There has never been a better time to be an engineer with special skills or the right education, because these people can use technology to create and capture value.*

*However, there has never been a worse time to be an engineer with only “ordinary” skills and abilities to offer: Employability competition is worldwide. Engineering students all over the globe, computers, virtual assistants and other thinking machines are acquiring these skills and abilities at an extraordinary rate.”*

*Brynjolfsson and McAfee (2014)*

Since it is TU Delft’s purpose to enable its engineering students to maximise their potential contributions to society at large and make a difference to the world by creative workable solutions (see the Mission Statement), its science-dominated engineering curricula should not only achieve technological depth in the engineering disciplines, but also enrich and broaden the students’ background. It shall be our purpose to help engineering students think about the bigger picture, let them see how the social, cultural and historical context influences the objectives, process and outcome of their research or design work, and that what they do is affected by global and social trends and may create unintended consequences. The time that engineering operated in a vacuum, separate from society, no longer exists. The learning of communicative, creative and interdisciplinary capabilities will become increasingly meaningful for students. They can, for instance, be implemented through inte-



*Main knowledge and capability areas for three career choices of an Engineering graduate, based on the Well-Rounded Engineer in McMaster's (2005)*

grated problem-based and challenge-based learning, or around historic cases and issues that are of personal and societal significance in the real world, in which disciplinary knowledge is used beyond its boundaries.

At the heart of the engineer lie defining and enabling capabilities. Engineering students are not only students of the subject matter of engineering, but also of problems and solutions that may very well go beyond their own expert domain in engineering, or even engineering at large. In their education we have to prepare them for basically three different engineering roles that they may play in their future careers. Firstly, we have to enable our engineering graduates to develop into a technical expert of world-class standing. Secondly, engineering graduates should be able to develop as an integrator who can synthesise, operate and manage across boundaries, be they technical or organisational, in a complex environment. Thirdly, our graduates should be able to take on the role of change agent, which means they must be prepared to provide the creativity, innovation, and leadership that is needed to guide research and industry to a successful future. During their study they must learn how to link science and engineering to the needs of society, and communicate that to the public. Most of today's engineers work in industry and research institutes and rarely interact on a one-on-one basis with people who directly benefit from their services,

as do physicians, lawyers, and teachers. This explains why at present the public is pretty unclear about what most engineers do.

The first challenge for engineering education is to anticipate the capabilities our graduates will need in their future jobs. “We have to educate students for jobs that don’t yet exist, using technologies that have not been invented, in order to solve problems we don’t even

*“Many programmes seem not even aware that there is a problem in focusing almost completely on technical knowledge and processes in their engineering curriculum.”*

*Grasso and Burkins (2010)*

know are problems yet” (Did You Know 3.0 - Shift Happens). It’s like packing for a holiday trip for which you don’t know where you will go. Students have to be prepared for practice to learn about the kinds of practical questions that engineering scientists and professionals in their domain repeatedly face. The second challenge is how faculty teach and students learn all that is needed to meet society’s needs and help solve the challenges in society

and engineering in the coming decennia. With accelerating speed we are moving towards a global collaborative society, in which traditional power structures are challenged by new market developments and values. No longer can engineering education be about assimilating knowledge alone. Mastering the challenges and opportunities in this fast-paced global society requires more than knowledge and basic engineering skills. In the next decennia our education has to emphasise how to apply knowledge to solve wicked and unstructured problems and how to act in a globally connected world. It has to be enriched to develop breadth, both professional and personal, such as self-management and managing relationships with self-awareness, social and emotional intelligence, and leadership. Our graduates have to be technically adept, broadly knowledgeable, culturally aware, able to demonstrate leadership, flexible and mobile, and have a concern for ethical issues, as well as be able to work collaboratively and think and design creatively. And they should have learnt how to communicate with the public. These requirements are not new, but their importance is growing.

The academic engineering degree has to remain a good preparation for a working life and continues to be seen as a good investment for employability. It looks almost unavoidable that major parts of our education in science and technology will have to be transformed into new paradigms to meet the growing demand for a new breed of modern engineers and to make optimal use of new pedagogical approaches and insights. They emerge from the rapid developments in the world that are caused by the forces of technology and globalisation. Curricular reforms should, however, not adversely affect the technical depth, as we do not want to endanger the strengths of our current education, scientific research and

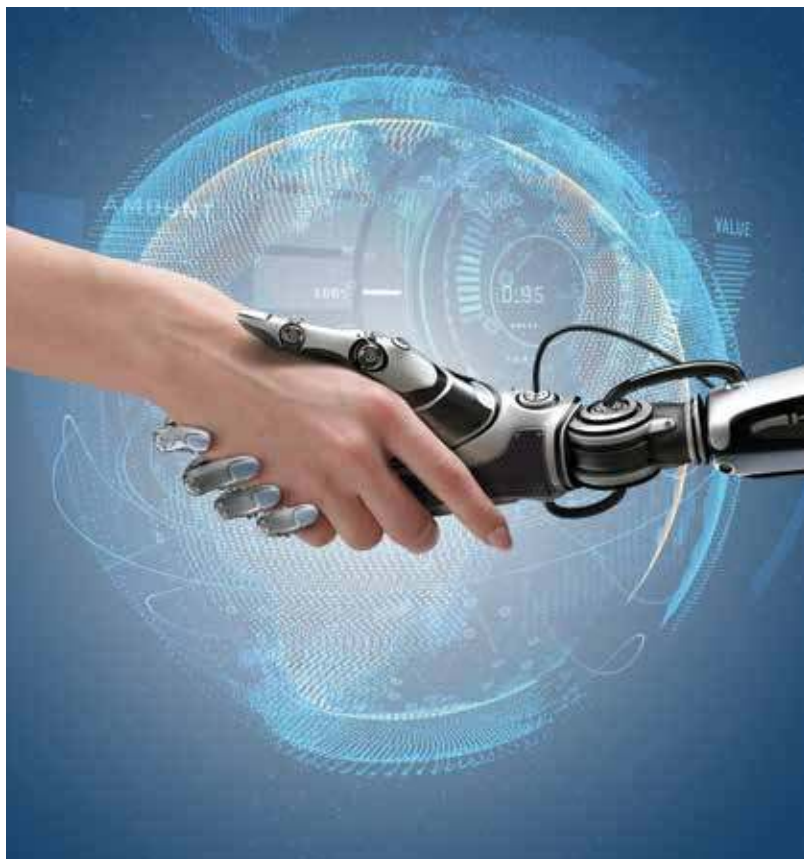
expertise in engineering and technological specialties. In other words, adding the required breadth and enrichment should not lead to teaching less and less about more and more. In the next decennia education in the engineering sciences must keep its emphasis on the fundamentals, but in a more balanced partnership with socio-economic factors, so that students see the profession of engineering as more than just an excellent preparedness in technical rigour. Since the residue of knowledge and habits of mind that students take away from an academic degree programme are greatly determined by how they are taught and how well they are taught; the how we teach will become equally or more important than the what and how much we teach.

*“80% of our economy is now information-based. Yet, if one would pursue an engineering degree from our university, the result would be many courses which are not significantly different from those offered during the middle of the past century, when Western Europe was largely a manufacturing-based economy.”*

*Grasso and Burkins (2010)*

*Engineering education in the 21st century, based on E.W. Ernst; Irene C. Peden (1998)*

Less emphasis on	More emphasis on
Vertical (in-depth) thinking	Lateral (functional) thinking
Abstract learning	Experiential learning
Reductionism	Integration – connecting the dots
Developing order	Correlating chaos
Understanding certainty	Handling ambiguity
Analysis	Synthesis
Research	Engineering design
Solving problems – the “how”	Formulating problems – the “what” and “why”
Developing ideas	Implementing ideas
Independence	Teamwork, collaboration
Techno-scientific base	Socio-economic context, the “big picture”
Engineering science	Functional core engineering



*Care robot of the future. Interactive robotics to enhance quality of life and self-reliance.*





# *Enabling the development of more than just cool technologies*

---

TU Delft's mission in its engineering education, combined with the trends and developments in higher education, the world of work and society, leads to a vision on engineering education that encompasses the following key aspects:

- ① *Rigour of engineering*
- ② *Critical thinking and unstructured problem solving*
- ③ *Interdisciplinary and systems thinking*
- ④ *Imagination, creativity, initiative*
- ⑤ *Communication and collaboration*
- ⑥ *Global mind-set: diversity and mobility*
- ⑦ *Ambitious learning culture: student engagement and professional learning community*
- ⑧ *Employability and lifelong learning*

These priority attributes are neither exclusive to TU Delft nor to the future. They have already been described in the “Criteria for Academic Bachelor’s and Master’s Curricula” by Meijers in 2005 and are the reference for the final qualifications of most if not all TU Delft Bachelor, Master and Excellence programmes. Most of the attributes have been mentioned in the past decennia in surveys and analysis reports about what universities think is best to teach, and what the world of work thinks is necessary. Although the attributes are not new, it goes without saying that their relative importance shifts because of a rapidly changing world, a result of modern technological developments, globalisation, the explosion

of knowledge, and the increasing complexity of the engineering and societal problems that have to be solved. It has become a cliché to argue that the twenty-first century engineering curricula would have to be reformed to shift the focus from “knowledge” to “capabilities”. We, the community of TU Delft educators, have the choice to what extent and how we want to embrace the shifts in learning outcomes.

In the past 15 to 20 years the accelerating rate of change in society has transformed our lives, business and global economy, but has not influenced the engineering educational

*“We have the choice of what type of engineer we want to educate: (“routine design engineers” - merely technically competent and designing complicated systems, “engineering scientists” - pursuing an academic career , or “holistic engineers” - trusted to make the important decisions in solving complex problems.”*

programmes as much. Universities hang on to past practices and change very slowly. In some ways this conservatism is positive; it encourages teachers to build upon well-established methods. But conservatism may go too far. Today is the worst time for complacency. We have entered an era where higher education in engineering may have to undergo fundamental changes, not only to benefit from pedagogical and technological innovations,

but also to align with the attitudes and capabilities of today’s students, and better prepare the graduates for the increasing and different demands of the new world of work. It is better to envision these changes, forecast the capabilities needed by tomorrow’s engineers and make choices about what type of engineer we want to educate (“routine design engineers” - merely technically competent to create, perfect and operate technologically driven processes, “engineering scientists” – pursuing an academic career, or “holistic engineers” - trusted to make important decisions in solving complex problems and taking on non-technical tasks of leadership), rather than wait for time to pass and then try to respond. Education has to change with the changing times. This time it may have to change deeper and more rapidly than it has in the past 40 years in order to strengthen the position of the profession of our engineers as a competitive, cost-effective, highly respected and attractive profession in the new world of work.

### 1 Rigour of Engineering

Without doubt the mastery of depth in technical engineering disciplines is necessary for successfully solving complex problems and advancing knowledge, now and in the future. To prepare students for the knowledge-based economy, engineering education has to focus on the acquisition and development of core knowledge and capabilities in the domain of

the engineering sciences : to discover, analyse, conceptualise, design, develop and operate complex systems. Future curricula will have to focus on discipline-based learning and emphasise the holistic view of a product and system life cycles, in which the students learn about physical phenomena, the engineering sciences, and how to transfer this knowledge into solutions and feasible designs. Students have to learn to alternate between the abstract and precisely detailed, to learn how to decompose big problems, model in words and diagrams, measure, and learn about orders of magnitude and measurement accuracies, and learn to accept failure.

*“You cannot understand or solve complex problems without the knowledge and tools of multiple disciplines.”*

In the 20th century, knowledge used to be the core capability. Already today, knowledge is no longer the destination of an engineering study but an on-going activity of learning-to-think and learning-to-learn. Tomorrow's engineers will no longer have to memorise all knowledge they learnt at school. The half-life of cutting-edge technology information is less than say five years, and much of what a student learns today will be obsolete a few years from now. Graduates will become the “grazers and collectors” of information and knowledge, using the digital world. It becomes increasingly important to shift our education from cramming large amounts of expert knowledge into the heads of the students, which primarily serves the needs of a minority of students who will pursue an academic career, to learning how to acquire knowledge from the surging sea of data, and how to find out what to make of it when it has been found. The future is that the internet is the true heart of the modern university, and Google is the omniscient librarian.

*“Graduates will be the “grazers and collectors” of information and knowledge, using the digital world.”*

Engineering is not a matter of applying science, of solving problems using the theories and methodologies of math and science alone, but also advancing knowledge through research. Besides the acquisition of education and the application of knowledge it is also essential to develop the student's independence, autonomy and critical attitude as well.

*“The core of engineering is not simply applied science, but the application of design and creativity to science.”*

If we take a look at the changes in subject matter, it must be expected that environmental literacy will become a basic literacy in higher education in engineering, while the massive

increase in sensors will unleash an incredible abundance of data and information (“big data”) that will require greater capabilities in data sciences (control and manipulation of big and small data through algorithms, programmes and scripts) and optimisation techniques in design, engineering and research.

## **② Critical Thinking and Unstructured Problem Solving**

The engineering sciences are often seen as the “trouble-shooter” when it comes to solving complex problems. Sometimes formulating the right question can already be a significant step forward. Critical thinking is about asking the right questions. The more complex problems are, the more data become available, the more vital the ability to ask the right questions becomes. The ability to ask critical and intelligent questions helps engineers to look outside the box and rethink the purpose of doing things. In the future, computer-based design-build engineering will be the norm for many product designs. Engineers and designers will be increasingly supported by virtual assistants, smart thinking machines that can complete cognitive tasks by employing artificial intelligence. There will be an increasing demand for the kinds of skills these machines are not good at: asking the questions and thinking outside the box. That makes critical thinking the single most important attribute our young graduates will have when entering the world of work.

The three most common kinds of problems that practicing engineers solve are decision making, trouble-shooting, and designing. For any of the three, solving the problem is more or less the same as defining it: there exists no stopping rule. Engineering students have to learn that solutions to engineering problems are mostly true or false, are defined as good or bad, and the stopping criterion is often “good enough”. They have to be made aware that engineering problems do not have an enumerable set of possible or permissible solutions. More emphasis in our curricula on solving unstructured real-life problems should make the students more familiar with the uncertainty of real problems.

## **③ Interdisciplinary and Systems Thinking**

Most graduates do not become discipline-based academics, while most promising innovations take place at the intersection of advanced specialties. A broad and strong intellectual base should be the foundation for any educational programme. A number of TU Delft programmes have therefore adopted the T-shaped professional as a reference: a deep specialist in one technical area and good knowledge and communication skills across some other (mostly technical) areas. However, the T of the T-shape in Delft often stands too much for Technology. To come up with valuable new breakthroughs in the future, engineers must

be capable of combining increasingly specialist monodisciplines (like robotic engineering, nanoscale engineering, biomedical engineering, virtual world and game engineering) and crossing borders and respecting other people's views. This leads to a clear need for expert thinking, but even more of a need for ability in complex communication: collaboration and multi- and interdisciplinary thinking will become increasingly important and this has to be reflected in a broadening of the bar as well as the stem of the T-shape with nontechnological capabilities. Furthermore, we have to be aware that an overspecialisation in especially the Master degree programmes may unintentionally prevent excellent students from reaching their leadership potential by the limited views and options they encounter in their study.

High-tech industries that develop complex systems and machines, increasingly look for engineers who have the capabilities to develop the outline for an integral design and keep the overview and take care of the consistency of the system design. These system architects not only need solid fundamental knowledge, but also must understand “the big picture”, have a sense of the multi-disciplinary problem domain and a good awareness of the business and human context. They must be able to reduce complexity, uncertainty and ambiguity to workable concepts. Engineering students have to learn what differences exist in methods of inquiry and arguments between the different disciplines, and how tools and materials of one discipline can illuminate the subjects of another. They need to learn how and when to incorporate social elements into a comprehensive systems analysis of their work. They have to learn how to solve problems in their complexity from a systemic perspective, drawing on multiple disciplines, seamlessly integrating multiple perspectives and methodologies by synthesising information, data techniques, tools and perspectives, and concepts or theories from two or more disciplines. Although the trend in research and higher education towards further specialisation continues unabated, many employees cry out for synthesis: the synthesising mind will become a highly valued mind in the 21st century. It is essential that we teach students more than we do in the current curricula, how to acquire more than one perspective on the same subject. Simply educating students in more than one engineering discipline, though, is not the solution to learning how to synthesise different disciplinary insights.

Different perspectives are also found in interdisciplinary engineering. Systems engineering and technical management have been a major foundation for technical leadership in complex systems design in military and space systems, particularly since the middle of the 20th century. Systems engineering is a vital component of engineering that helps in the solution of complex multi- or interdisciplinary problems. But the technically oriented systems engineering in the future may have to shift to Enterprise Systems Engineering. To

design systems that can perform as components of large-scale complex enterprises, future systems engineers must have learnt to look beyond the system itself, and consider the characteristic of the enterprise in which the system will operate and the context in which the system is developed. Systems engineers will be transformed from the architects who guide engineering projects for clients from concept toward strategic goals, to leaders who are capable of balancing their technological skills with the demands of restricted budgets, regulatory frameworks, collaboration complexity, public safety impact and public understanding. It is these “people” components that introduce much of the uncertainty and complexity into engineering projects. The education of systems engineering methodologies will see a transformation into a framework of complex systems science that comprises political/social, operational, and economic aspects, besides those of engineering. With more engineering resources being devoted to solving complex engineering problems from the microscopic level of information and communication technologies, new materials and nano- and biotechnology to the macroscopic level complex systems of mega cities, wind farms and global systems such as cyber-infrastructures and civilian airspace navigation, there will be an increasing need to cover Enterprise Systems Engineering and technical management as essential interdisciplinary elements that each engineering student should learn in his or her academic life.

Learning interdisciplinary and systems thinking shall not be limited to the engineering domain: engineering no longer has a life of its own. Almost any practice of engineering will involve team-based, cross-disciplinary projects. The ability to apply theory to difficult problems in collaboration with other people will be a key attribute for engineers who want to be innovators. Learning-by-doing-(together) in real-world, authentic problems and encouraging risk taking must become an important aspect of future educational programmes. Interdisciplinary thinking requires the synthesising of disciplinary knowledge and stakeholder knowledge (pulling together what is known about a problem from both academic knowledge and practical

*“The days of engineers creating systems and processes without an understanding of the impact created by the end product are over. Engineering no longer has a life of its own.”*

experience) and the understanding and managing of diverse unknowns (appreciating that everything about a complex problem cannot be known and that the remaining unknowns must be taken into account in decision making). Future education has to address interdisciplinary problem-solving techniques in which not only different engineering disciplines are involved, but also the social and human factor. It may require a change in educational approach, with students taking courses from fields that traditionally are not taught in engineering programmes. But this will enable them to compare, contrast, connect and adjust

disciplinary concepts, theories and methodologies. Such courses help students form a deeper understanding, see the bigger picture, make the curriculum more relevant to them, and build connections among central concepts within mostly mono-disciplinary engineering and across its interfaces with other disciplines. These capabilities will provide our graduates with integrated engineering and research approaches that give all stakeholders who are involved in a problem a better understanding in a way that supports them in making decisions.

#### 4 **Imagination, Creativity, Initiative**

Where “global knowledge” was once essential for leaders, “creativity” will be the most important leadership quality for the engineer of tomorrow. Creativity depends on connecting disparate dots of knowledge, and more often than not this is driven by collaboration as much as, if not more than, by solo work. We have to teach the students to think more horizontally, to mesh together different perspectives and disciplines. Given the speed of change and the complexity that results from this, students have to learn to go beyond knowledge, expertise and logical analysis, and develop a

*“Creativity will be the most important leadership quality for the engineer of the future.”*

courageous attitude towards being creative and addressing different ideas. Leaps in science and engineering often result from unexpected leaps of imagination and are made intuitively. Intuition requires an open mind where the main thinking is more about what-to-do than how-to-do it. It is a capability that is often associated with the concept of entrepreneurial engineering. Engineers in the future will only be able to excel at creative problem solving and different ways of thinking when they have learnt to see the world through the eyes of a practitioner from a different discipline, and are able to combine logical analysis with intuition.

In the future world of work, engineering functions that can be broken down into a sequence of clearly defined (not necessarily simple) actions are ultimately easily duplicated, and therefore a likely and safe candidate for outsourcing to low-cost countries. These functions are also prime candidates for automation and so engineers in the future will be increasingly supported by thinking machines that can complete cognitive tasks. Ideation and coming up with new ideas or concepts is something that computers cannot do. What-to-do engineering, in combination with technological excellence, is a capability that is difficult to

*“Bachelor student experience has to bear out the creativity and innovation promise of careers in engineering.”*

*Grasso and Burkins ( 2010)*

duplicate, automate, or outsource and so it may be expected that what-to-do engineering will grow into a core capability for tomorrow's engineer.

Engineering education has to shift from predominantly the feeding of information into enhancing the development of the student's right brains, by forging relationships rather than executing transactions, tackling novel challenges instead of solving routine problems, and synthesising the big picture, considering problems from different perspectives, rather than analysing a single component. "If you don't educate

*"If you don't educate creativity, you kill it."*

creativity, you kill it." Creative engineers do not develop from passive learners. To awaken curiosity and an open mind in our classes we have to pose more challenges and thresholds to the students' thinking. Only then will the students develop the required capability of creative thinking. Courses or educational

projects in systems design should not only teach the logical sequence of design steps that professional engineers take but stimulate creative thinking with open-ended formulations and questions. We have to offer the students self-directed learning environments in which there are no "stupid" questions and no "right" answers, with a high level of self-regulation and much active and hands-on learning, such as in projects where students conceptualise, design, build and test experiments, machines and systems. This is clearly illustrated by the abundance of user-generated videos and maker communities on the internet, but also by the extracurricular student projects at TU Delft. Creating more such study environments in the curricula would give students the freedom to take risks, and allow them to discover and develop their own intelligence.

Innovation requires whole-brain thinking — right-brain thinking for creativity, imagination and holistic system thinking, and left-brain thinking for logical reasoning, analytical thinking and planning. Creativity and innovation can be stimulated by taking students far out of their comfort zone, by bombarding them with things they've never encountered before, by giving them challenges in design projects by creating "immigrant mind-sets", by creating opportunities for studying abroad or placements in industries or institutes in different business, cultures or environments. Also, the classroom environments themselves create ambiances that may encourage or discourage imagination, creativity and innovation.

## 5 Communication and Collaboration

Engineering practice involves team-based, cross-disciplinary projects. Our graduates will work in a globally connected world with international and multicultural collaborative teams, whose members may work on different continents in different cultural settings and



different time frames. They will use complex communication techniques through social networking and interaction, both virtual and face-to-face, using ever changing tools, from email to Skype to virtual meetings and more. Advancements in technology continuously redefine how engineers communicate, as global collaboration, mobile computing, and 24/7 product development permeate practice. Digital work, however, makes working relationship more complex: although the teams are more connected, the social relationships are more fragmented and impersonal than 20-30 years ago. The emergence of new technologies also means that engineering communication no longer involves just oral presentations and writing technical reports. Engineering graduates need broader basic communication capabilities and need to develop e-mail writing, synchronous chat technologies, virtual conferencing systems, mobile phones, web-based collaborative tools, cloud data management, and whatever the next wave of development will bring. As communication technologies will continue to shift, and work becomes increasingly distributed, engineering students have to be trained to develop a fluency, not only with written texts on paper, but with the full range of communication media. In their studies they have to experience how those media support and hinder an effective workplace.

Students also have to learn the language of discourse of their own engineering discipline and the ones that interface; how to explain difficult concepts to different audiences and what misconceptions, preconceived notions, and biases people bring to learning. Learning to communicate as an engineer is strongly related to learning to think like an engineer. It is therefore essential that we enhance the education in which students learn to work with diverse groups and to use learning and collaboration technologies. These capabilities are valuable

for careers in academia, industry, government, as well as not-for-profit organisations. In their communications students have to learn that data can be interpreted in diverse ways,

and that they need to convince others that their designs or services are efficient, useful or otherwise sound. Given the high stakes associated with communication in engineering and the rapid technology development cycles at play in global engineering, it may no longer be feasible to allow students the luxury of time on the job “to figure it out for themselves”. Employers are willing to invest only in training

*“Students have to learn the language of discourse of their own engineering discipline and the ones that interface; how to explain difficult concepts to different audiences.”*

*“Our Master’s is just two years. In their career they have more than 40 years to learn those skills. It’s not our responsibility to prepare them for a career.”*

*Professor in Aerospace Engineering,  
Management Retreat March 2014*

only for those skills whose value they can fully capture, but are less willing to invest money on knowledge or basic skills development since the employees might take that expertise elsewhere.

Engineering graduates usually impress with their technical abilities, but they are often mute when it comes to discussing “the big issues”. As technology becomes increasingly ingrained into every facet of our lives, the convergence between engineering and public policy is expected to increase. This new level of interrelatedness necessitates that engineers develop a broader sense of how technology and public policy interact. It becomes increasingly important to give students a zest for reasoned and informed debate of societal issues. They have to be trained in how to participate in debates with the public about more controversial areas of engineering, not only with engineers but also with business leaders, politicians, financial managers and lawyers, people with backgrounds in the social sciences and humanities, from different cultures, or with different needs and interests. This requires discussion and empathy rather than a didactic approach. When graduates master this wider range of communication skills, they will find it easier to persuade, influence and lead.

### 6 A Global Mind-Set: Diversity and Mobility

Distance, space and time are no longer boundaries for the practice of engineering. The flattening of the world and the interconnectedness of the world of work intensifies the demand for engineers who are capable of performing in culturally diverse contexts. University students, whether they prepare for an international career or not, will live and work in a context that is highly international, and will be surrounded by people of diverse cultures and traditions. They have to be able to operate in, mobilise, inspire, and manage a multidimensional and multicultural workforce. Engineers in different countries define and solve problems differently, and these differences create problems that have to be taken into account while working on global teams. Information technology creates immense opportunities for collaboration across time and space, but also generates boundaries that inhibit interpersonal interaction.

An international atmosphere on campus can help but is not sufficient to learn about problems in interpersonal interaction. Intercultural and globalisation content should be embedded in the engineering curricula. This will also allow “internationalisation at home”, where students can learn to effectively deal with ethical issues arising from cultural or national differences, understand the implications of cultural differences on how

*“Cultural awareness and creativity are essential capabilities that engineering students have to develop to be able to compete in a globally integrated society.”*

engineering tasks are approached, and understand cultural differences relating to product design, manufacture and use. Our multicultural classrooms are good resources that we should use purposefully in developing these intercultural skills. They can allow the students to learn how to work effectively in such surroundings and develop a global mind-set, even if they stay on campus. In class the students have to learn to be agile and adaptable to new cultures and get their first experiences in how to collaborate in teams, whose members have different levels of knowledge, skills, attitudes and habits, and operate in different economic, political, legal and social and information environments. The available diversity on campus offers creative intercultural opportunities, and this route to enhancing intercultural capabilities is on our doorstep already.

Tackling and surmounting new challenges and unfamiliar situations increase student's self-confidence and ignite their curiosity. Personal leadership, responsibility, social and cross-cultural skills are, for instance, enhanced through an experience in studying abroad, when students reflect upon their life experiences. These experiences can already be accommodated through partner universities, but could be stimulated, for example, by setting up a network of TU Delft project centres around the world to facilitate on-location intense experiences of interdisciplinary project work, typically involving a high degree of interaction with the local people and culture. A boost in the development of interpersonal skills and adaptability is a major reason why an experience abroad greatly increases the versatility of young graduates. Such a boost only happens when the international experience is "purposeful", that it not only exposes students to new cultures, but also requires that the time spent abroad involves team building and collaborative learning, interdisciplinary exposure and different ways of communicating. In this respect we should also stimulate teaching staff to be much more mobile in the international engineering world. Peer learning is achieved by sharing the best practices with academic colleagues abroad and industrial professionals.

Globalisation enhances the number of potential students who "shop" globally for the best offerings in higher education. Technical universities will become more diverse by, among others things, the international influx and increase in student exchange. This diversity enriches the study culture. Diversity is expected to further grow by an increased individualisation through the DIY approach (Do It Yourself), in which students learn more

*"Students have to learn the language of discourse of their own engineering discipline and the ones that interface, how to explain difficult concepts to different audiences."*

*"Diversity is expected to grow by an increased individualisation through the Do It Yourself approach."*

and more off campus of what we used to learn on campus, through media, online distant learning, the internet and from different social networks to which they belong. Technology and innovation are creating increasingly attractive alternatives to existing educational formats, and the students will learn quickly how to take advantage of those. Just like buying individual songs with iTunes instead of complete albums, students will shop around, pick different components of education from different sources, all in service to their individualised approach to “being educated”. Student engagement that is currently achieved by teaching that is drawn from standard curricula, may soon have to change into more individual learning plans, enabling more flexibility. As students spend an increasing amount of their private lives online, they expect that their study environment will similarly have an online presence. This raises questions about how our curricula should respond to these demands. New opportunities may emerge from combining online learning technologies and face-to-face pedagogical strategies by adopting new models for blended learning. They may appear an effective means to enhance flexibility and accommodate the larger diversity in learning styles and study cultures.

Increasingly young engineers will be within reach of jobs and potential customers anywhere in the world. But they will also be in competition with the best talents in the world: engineers are proliferating at an enormous rate in the global world of work and the massifi-

cation of higher engineering education is enormous. Nowadays already more than 40% of the global total of higher education students study in the low-cost countries Brazil, China, India and the Russian Federation. How can we enhance the quality of our education and train our students so

*“How can we educate our students so that they offer capabilities that are not available in the global market for a fraction of the cost?”*

that they offer capabilities that are not available in the global market for a fraction of the cost? By any means our graduates should have a strong profile and be well-connected to the global market.

### **7 Ambitious study culture: Student Engagement and Professional Learning Community**

Engineering education should be engaging, compelling and motivating, and create a learning community that stimulates all students to discover their talents. The aim is to create a climate in which students are encouraged to develop ideas, both big and small, and bring to the market creative solutions to real world problems. Such a climate can be achieved by focusing on the student as the key player in the learning process (student-centred learning) and by an emphasis on experiential learning: teaching when the need for it has been estab-

lished. Curricula have to focus on coherence, leading to a degree and a connection between courses. They should connect the subject matter to the context of the students' lives and

*“Besides technology, I have always been interested in social issues, international affairs, arts and culture and I think these will be essential in my future job. I wish I could develop these interests to a higher level, but being a student at a technical university makes this difficult. Aerospace Engineering is challenging and very interesting but does not include any of these topics.”*

*Yvonne, student MSc Aerospace Engineering, Sep 2014*

the engineering profession, like the pressing issues of environmental awareness, social responsibility and entrepreneurial thinking. These issues connect with many young hearts and minds, which is proven by the great interest, ambition and commitment in the D:DREAM student projects, as well as the excellence programmes that offer exactly these opportunities, unfortunately for a limited few.

Experiential opportunities in labs and project and production spaces foster strengths beyond the technical experiences like leadership and ethical behaviour. Such integrative aspects in a curriculum address real-life concerns, present better opportunities for problem solving, promote student's independent learning, and offer a more effective involvement with the engineering environment and society. It is absolutely essential that the students

experience the real world of engineering and have a taste of genuine research by learning-by-doing and getting lectures and coaching by our professors, experts and researchers in the Bachelor, as well as the Master programmes. Research, experimentation in labs, hands-on design projects on authentic problems, build and test projects in project and production spaces, and internships in industry and institutes enhance student engagement and let students learn how to develop and monitor their own development and learning, and allow for more application of learning outcomes to real life. Through trouble-shooting and the production of a design, students are brought face to face with the social purposes and consequences of engineering through the technologies it creates, the practice of manufacturing, the management of people, and the personal skills.

In a time where the classroom environment is evolving from a room-with-a-blackboard to a laptop-with-a-network connection to the cloud and an online forum, challenges may be the finding of ways to bring design-oriented, project-based learning and hands-on experiences to online learning, blended with in-person, hands-on activities in real labs. The rise of new technologies such as virtual and augmented reality makes it easier and easier to simulate in-person experiences at a distance. This technology, along with ubiquitous content and instant multiple channels of communication, will be able to deliver the experience of rich

interactions in a lab or a classroom with one's peers regardless of location and time. Virtual and remote labs may offer expanded access to experimental set-ups in the labs, and remove the need to be on campus for experimentation and design-build-test projects. Virtual labs are simulations that visualize physical phenomena; remote labs provide an interface to remote equipment in the real experimental facilities. They are not an equivalent substitute for an in-person experience and should therefore not be simply cut-and-pasted into a curriculum, but may support the achievement of certain learning outcomes. Part of the hands-on learning may be transformed into hands-off learning by serious game simulations of lab environments. We can make them an invaluable tool for supplementing existing laboratory work for a large number of students. In the near future remote labs will shift from using a specific piece of equipment to accessing a network of shared facilities between universities or faculties. We should avoid that students who use simulations of hardware lose sight of the real hardware being simulated, and instead get caught up in the "computer game" attitude toward the software. Above all, it should not be neglected that real fabrication and experimentation in lab spaces are places where engineering students bring their ideas to life and share their passion for making and testing things. They come to our university for more than just an engineering degree, but also to develop personally. In the classrooms and the physical labs they learn a great deal from their classmates, and much that they learn is not strictly academic. They gain the most from one another if their classmates have different interests, experience, talents and beliefs. The physical lab spaces therefore will remain essential for learning how to engineer, and more importantly, may be a place for innovation and experimental play.

*"The physical lab spaces remain essential for learning how to engineer, and more importantly, may be a place for innovation and experimental play."*

To engage the students with authentic complex problems, we may use case histories and global challenges as subjects in our educational work in interdisciplinary minors or projects. Integrating case histories into the educational process promotes a positive identity of the engineering profession and a sense of tradition—things that engineers often lack relative to medical doctors and lawyers. Case histories often point out in a variety of ways how social systems or technical infrastructures have compromised the success of a seemingly appropriate technical approach. Studying successes of innovative engineers in courses may also help students understand the roots of imagination and innovation. It could also be interesting to let students work on design projects, critically watched over by a competing team that traces weaknesses in design and analysis. The competing teams could discuss these weaknesses until the debate is closed. Such checks and balances imply a continuous

deliberation between engineering students. Students thus learn that mistakes and weaknesses can be signalled by peers, maybe even from other disciplines.

When immersed in authentic complex problems, students grapple with the uncertainties of evidence, the construction and communication of scientific positions and arguments, and the societal and ethical contexts of the latest developments in science, engineering and technology. Addressing such challenges highlights for the students the crucial role their own discipline plays in thinking about these challenges, while giving them an appreciation of the other disciplines. The broader view stimulates their thinking about careers beyond academe and provides them with the insights, skills and confidence to succeed at job interviews. It is an important asset in our education to convey the role models and knowledge about professional requirements to the students.

To capture student interest and respect, training in ethical responsibilities should be more interwoven with subjects that are already taught and should no longer be on the margins of the curriculum. To develop a good sense of ethical accountability and social responsibility, students need to come in closer contact with senior engineering professionals with whom they can identify and try to emulate. Long-term enhancements in labour market relations for university teachers are therefore essential to ensure good contact with the labour market that graduates are expected to enter.

Student engagement requires a professional learning community of lecturers where learning is sparked by personal knowledge and the ability to engage others, with passion and creativity, and where teaching staff have joint sponsorship of learning outcomes and study results. This requires a culture and climate where the staff is willing and able to work as a team, serving as a powerful role model for the students. The academic staff will have to develop a more holistic engineering mind-set to be able to enrich the learning process and demonstrate that engineering is all about knowledge integration. Strengthening didactic professionalism of and trust in teaching staff shall be the norm. Since the Graduate School is an important source of new academic staff, its training programme, and that of the tenure track programme, it deserves careful scrutiny concerning the problems and future needs of education at our university.

A major challenge for the academic staff is created by the fast developments in the digital world. The social-media connectivity has been growing very rapidly with the proliferation of mobile devices, and the penetration rate of mobile devices among students has reached a record high. Emerging digital tools make it easier for students to ask and respond to each other's questions and for teachers to provide feedback in real time. State-of-the-art

real-time response systems will allow faculty to better monitor student learning and provide immediate advice during live classes. Although much of the senior staff is not a digital native but more a digital immigrant, they can no longer afford to ignore these tools. With the revolutions in the technological landscape, digital media literacy will continue its rise in importance as a key skill for our lecturers and professors. A major effort will be needed in the foreseeable future to make sure that our staff can support the students, helping them to develop and use digital literacy skills across the curriculum. Also, the rise of data-driven learning and assessment, in which data on personalised learning experiences and study results can be mined for new pedagogical insights, will pose new demands on staff capabilities in learning analytics.

### 8 **Employability and Lifelong Learning**

Employability is defined as a learning process, a graduate's achievement and the potential to acquire a job. Although the aspect of employability has to be considered in the matching of professional engineering skills to industries and institutes, it should never be the single driver for the intended learning outcomes of an engineering programme. One of the most important employability skills is "learning how to learn". Employees in the future will change jobs more than in the past. They need to be more adaptable and flexible, by which is meant the ability to learn a new job when the one they are in becomes redundant. For this they will require a wider and more uniform form of knowledge than in the past. Hence, an important challenge is to design curricula that

*"It is not only what you know, but how you learn that will set a young graduate apart."*

are not only a preparation for a career in a particular discipline, but rather as the foundation for a lifetime of continuous learning. The emphasis in our educational process will have to shift from the mastery of subject knowledge to a mastery of the learning process itself. Students need to become self-motivated, active agents prepared to take responsibility for their own learning and skill development. They need to understand how to create value to receive value and act as the entrepreneur of their own career.

In the new world of work it is not only what you know, but how you learn that sets you apart. Education, with an emphasis on broad skills, will enable the students to go on through life acquiring new capabilities. At graduation, students will have learnt to be adaptable and versatile, to apply the depth of their capabilities to a progressively

*"The challenge is to design the engineering degree programmes not as preparation for a career in a particular discipline, but rather as the foundation for a lifetime of continuous learning, as a preparation for their last job."*



widening scope of situations and experiences, thus gaining new capabilities and building relationships. These are the tools that will enable young engineering graduates to take on responsibility early, to have diversified career paths and meaningful work, meeting ethical standards with professional responsibility. They will make them more employable for a lifetime, more able to acquire the knowledge or the experience that is needed to be a good adapter, synthesiser and collaborator.

In our system of education the students will be made aware that they can only succeed in their profession if they develop their own personal capabilities. Young adults will need to

*“Students have to learn that they will only succeed in their profession if they also develop their personal capabilities.”*

prepare themselves for a lifetime of continuous up-skilling and development, by not only applying the knowledge they already learnt, but acquiring new knowledge as needed. Internships, as a compulsory element in the curricula for instance, make it more likely that young engineers will come to understand the big picture

and the need to learn: how context shapes the tasks and how contingency factors have to be integrated into performance. Particularly internships abroad have a strong impact on learning, even more than studying abroad at a university. Students working in industry may by chance also be exposed to innovative and entrepreneurial activities. Thus, they pick up the capabilities and experience of entrepreneurial engineering like strategic technology planning, development processes, new concept ideation, technology needs assessment, and technology road mapping. Interacting with modern engineering professionals in design or research projects is the key to providing students with the role models for their future and exposes them to real-world professionals and the problems engineers face every day. The ERASMUS impact study “Effects of Mobility on the Skills and Employability of Students and the Internationalisation of Higher Education Institutions” shows that one out of three students who took an internship were offered a job by their host company, and one out of 10 of them started their own company. Industrial internships have not only a more positive impact on the development of professional and personal skills, they also create better employment and career prospects.

Practicing engineers value lifelong learning skills. They are prepared to continue learning, and proactively plan for self-improvement and their future career. Reflective skills, particularly, are critical to being an effective, self-directed lifelong learner. As professionals move through their careers, they direct their own learning.



*Future airport.*

To ensure we are educating the most talented and effective engineers, TU Delft has to ensure that it is also providing continuing education for them throughout their careers. The university has ample opportunity to offer multiple options, face-to-face, blended, and online courses, focused on learning- by-doing, individually, in groups, and from each other, and produce these trainings on campus or online. Computer-based trainings will become common practice in lifelong learning.

Lifelong learning will also apply to the teaching staff, to routinely update their pedagogy and develop new learning environments that are based on proven practices. They shall also be able to incorporate future needs in their subject matter, perform synthesis in balance with analysis, act as a catalyst and integrator in multifaceted interdisciplinary projects, and build connections between the world of learning and the world of work. They will have to develop pedagogical knowledge and capabilities in relation to their personal needs and stay up-to-date with the developments in engineering education, such digital literacy, the flipped classroom, the transfer of MOOC experiences into campus education, or changing the approach from “assessment of learning” into “assessment for learning”.



# Conclusion

---

Over the last couple of decades the world around us has changed at a dizzying pace. The ways we communicate, work, travel and do business have changed dramatically, and are expected to change at an even faster pace in the future. There is a world that has been extremely conservative: the world of higher engineering education. It still stresses capabilities that are no longer critical in the new world and seems to ignore those that are gaining prominence.

In the 20<sup>th</sup> century engineering education focused on the underlying scientific and technical content, neglecting the socio-economic aspects of engineering. Engineering seemed to have a life of its own. The new world of work, however, calls for a more holistic approach to engineering education. We can no longer just produce graduates who are well-versed in technical functionality. The new breed of bright technical minds have to understand how to help solve the societal and engineering challenges of the 21st century through creative workable solutions, whose performance and function not only depend on technology, but also on the socio-economic context within which they operate. Engineering education can only be future-proof if it ensures that its outcome does not only lead to an excellent preparedness in technical rigour, but also in operational capabilities for creative thinking, leadership and decision making that are required to lead successfully and solve complex projects.

What are the most important capabilities that engineering graduates will need in their future careers? This is a question that is being universally asked as universities and companies are contemplating the next generation of academically educated engineers. And it has become a cliché to argue that the future engineering curricula will have to shift focus from “knowledge” to “capabilities”. A broad fundamental knowledge in the engineering sciences,

## Conclusion



*Future aircraft. Design of a sustainable and environmental-friendly aircraft.*

systems thinking, interdisciplinary thinking in which engineering domains as well as socio-economic factors are considered, creative thinking, communication and collaboration, and a global mind-set, are the key capabilities for the engineer in the 21st century. These attributes are not new, but their relative importance is shifting and will shift further in the coming decennia. There is a strong consensus that the most important capability that an engineering graduate should have is a positive attitude towards lifelong learning. In the new world of work it is no longer what an engineer knows, but how he learns and is able to apply what he learns that makes his career successful. Lifelong learning is the most important employability skill for the engineer of the future.

Quite a number of programmes show a dangerous sense of complacency, or seem insufficiently aware of the growing mismatch in focusing almost completely on technical knowl-

*“The OECD is signalling that higher engineering education is losing the race with the pace of innovation in technology and in the skills-demand of 21st century economies and the many social changes of contemporary globalised societies. At the same time significant reform is often difficult.”*

*OECD Centre for Educational Research and Innovation,  
October 2014.*

edge and processes in their engineering curricula. We have entered an era where higher engineering education will have to make fundamental changes, to take the benefits of the pedagogical and technological innovations, and better prepare graduates for the increasing and different demands of the new world of work. It is better

to envision these changes and make choices on how to adapt the education than wait for time to pass and then try to respond.



# Bibliography

---

Advisory Council for Aviation Research and Innovation in Europe (ACARE); Challenge 5 - Prioritising research, testing capabilities and education. In Strategic Research & Innovation Agenda Volume I; Realising Europe's vision for aviation (p.p. 121-138), Brussels, 2012.

Al-Atabi, Mushtak; Think Like an Engineer: Use systematic thinking to solve everyday challenges & unlock the inherent values in them; Taylor's University, Selangor, Malaysia, 2014.

Bammer, Gabrielle; Disciplining Interdisciplinarity, Integration and Implementation Sciences for Researching Complex Real-World Problems, The Australian National University Press, Canberra, 2013.

Barber, Michael; Donnelly, Katelyn; Rizvi, Saad; An Avalanche is Coming; Institute for Public Policy Research, London, 2013, retrieved August 13, 2014 from <http://www.ippr.org/images/media/files/publica->

[tion/2013/04/avalanche-is-coming\\_Mar2013\\_10432.pdf](http://www.ippr.org/images/media/files/publication/2013/04/avalanche-is-coming_Mar2013_10432.pdf).

Basken, Paul; Boeing to Rank Colleges by Measuring Graduates' Job Success; The Chronicle of Higher Education; issue date 19 September 2008; retrieved 15 September 2008 from <http://chronicle.com/weekly/v55/i04/04a00102.htm>.

BusinessEurope; Plugging the Capability Gap, The clock is ticking (science, technology and maths); Brussels, 2012.

Blackmore, Paul; Kandiko, Camille B; Strategic Curriculum Change, Global trends in universities; Routledge, Oxon, 2012.

Bok, Derek; Higher Education in America; Princeton University Press, Princeton, 2013.

Brynjolfsson, Erik; McAfee, Andrew; The Second Machine Age, W.W. Norton & Company, Inc., New York, 2014.

## Bibliography

- Christensen, Clayton M., Eyring Henry J.; *The Innovative University: Changing the DNA of Higher Education from the Inside Out*; Genetic Reengineering (part five), Jossey-Bass, San Francisco, 2011.
- Clough, G.W. (chair); *The Engineer of 2020: Visions of Engineering in the New Century*; National Academy of Engineering; The National Academies Press, Washington DC, 2004, retrieved 30 June 2014 from <http://www.nap.edu/catalog/10999.html>.
- Clough, G.W. (chair); *Educating the Engineer of 2020: Adapting Engineering Education to the New Century*; National Academy of Engineering; The National Academies Press, Washington DC, 2005, retrieved 30 June 2014 from [www.nap.edu/catalog/11338.html](http://www.nap.edu/catalog/11338.html).
- Cohen, Martin, *The Knowledge Revolution*; in *University World News*, global edition number 331, retrieved 29 August 2014 from <http://www.universityworldnews.com/article.php?story=20140820110708346>.
- Crawley, Edward; Malmqvist, Johan; *Rethinking Engineering Education*; Springer Science and Business Media, 2007.
- Czerniak, Charlene M.; *Interdisciplinary science teaching*. In *Handbook of research on science education* (pp.537-559); S. K. Abell & N. G. Lederman (Eds.); Routledge Taylor & Francis Group, New York, 2007.
- Dammer, Dirk van (OECD); *Toe aan rust? Nee, er is storm op komst; Het hoger onderwijs dreigt de wedloop te verliezen*; in *THEMA Hoger Onderwijs* ([www.themahogeronderwijs.org](http://www.themahogeronderwijs.org)), 2014, number 3, pp. 35-38.
- Davies, Anna; Fidler, Devin; Gorbis, Marina; *Future Work Skills 2020*; Institute for the Future for the University of Phoenix Research Institute; Palo Alto, 2011; retrieved 20 October 2014 from [http://cdn.theatlantic.com/static/front/docs/sponsored/phoenix/future\\_work\\_skills\\_2020.pdf](http://cdn.theatlantic.com/static/front/docs/sponsored/phoenix/future_work_skills_2020.pdf)
- Deci, Edward L.; *Why we do what we do: Understanding Self-Motivation*; Penguin Books, New York, 1996.
- Dertouzos, Michael L.; Lester Richard K.; Solow, Robert M.; *Made in America, Regaining the productive edge*; Harper Perennial, New York, 1990.
- Duderstadt, James J.; *Engineering for a Changing World; A Roadmap to the Future of Engineering Practice, Research, and Education*; The University of Michigan, 2008, retrieved 24 August 2014 from <http://milproj.dc.umich.edu/>.
- Ernst, Edward W.; Peden, Irene C.; *Realizing the New Paradigm for Engineering Education*, Proceedings of Engineering Foundation Conference; Baltimore, June 3-6 1998; retrieved 5

October 2014 from [www.gateway.vpr.drexel.edu/files/Engg\\_Education.pdf#page=32](http://www.gateway.vpr.drexel.edu/files/Engg_Education.pdf#page=32).

European Union; The Erasmus Impact Study; Effects of mobility on the skills and employability of students and the internationalisation of higher education institutions; Publications Office of the European Union, Luxembourg, 2014; retrieved 13 October 2014 from [http://ec.europa.eu/education/library/study/2014/erasmus-impact\\_en.pdf](http://ec.europa.eu/education/library/study/2014/erasmus-impact_en.pdf).

Executive Board of Delft University of Technology; Roadmap TU Delft 2020, Freedom to Excel, Delft University of Technology Strategic Plan, Delft, 2010, retrieved 15 March 2014 from <http://www.tudelft.nl/en/about-tu-delft/strategy/strategy-roadmap-tu-delft-2020/faculty/ud-ovdo/>.

Friedman, Thomas, L.; *The World is Flat, A brief history of the twenty-first century*, Release 3.0, Picador, New York, 2007.

Gardner, Howard; *Five Minds of the Future*; Harvard Business Review Press, 2009.

Goldberg, David E.; Sommerville, Mark; *A Whole New Engineer: The Coming Revolution in Engineering Education*; ThreeJoy Associates, Inc., Douglas, Michigan; 2014.

Graham, Ruth; *Achieving excellence in engineering education: the ingredients of*

successful change. The Royal Academy of Engineering, 2012.

Grasso, Dominico; Burkins, Melody B. (Eds); *Holistic Engineering Education, Beyond Technology*, Springer Verlag, New York, 2010.

High Level Group on the Modernisation of Higher Education; Report to the European Commission on New modes of learning and teaching in higher education; Publications Office of the European Union, Luxembourg, October 2014, retrieved 4 November 2014 from [http://ec.europa.eu/education/library/reports/modernisation\\_en.pdf](http://ec.europa.eu/education/library/reports/modernisation_en.pdf).

ICF GHK, for the European Commission; *EU Skills Panorama, STEM Skills Analytical Highlight*, retrieved September 11, 2013 from <http://euskillspanorama.ec.europa.eu>.

Institute-wide Taskforce on the Future of MIT education, Final report, MIT, Massachusetts, 2014, retrieved 29 August, 2014 from [http://web.mit.edu/future-report/TaskForceFinal\\_July28.pdf](http://web.mit.edu/future-report/TaskForceFinal_July28.pdf).

Jamieson, Leah; Lohmann, Jack R.; *Innovation with Impact, Creating a Culture for Scholarly and Systematic Innovation in Engineering Education*; ASEE, Washington, 2012, retrieved 14 March 2014 from <http://www.asee.org/member-resources/reports/Innovation-with-Impact>.

## Bibliography

- Johri, Aditya; Olds, Barbara M; Cambridge Handbook of Engineering Education Research, Cross-cutting Issues and Perspectives (part 6); Cambridge University Press, New York, 2014.
- Jones, Elspeth; Internationalisation and Employability: Are we missing a trick? Forum, Winter 2012, EAIE, Amsterdam 2012.
- Kamp, Aldert; Educating tomorrow's innovative engineers to maintain Europe's leadership in aerospace; CEAS Quarterly Bulletin, pp. 47-49, December 2013.
- Kirkpatrick, Allan T.; Vision 2030, Creating the Future of Mechanical Engineering Education; ASEE, Washington, 2011; retrieved 24 August 2014 from <http://www.asee.org/public/conferences/1/papers/2804/download>.
- Kos, Timo; Touw, Ellen; van Noort, Elco; Strategic Plan, Internationalisation of Education 2014-2020, Delft University of Technology; Delft, 2014.
- Marshall, Stephanie, Strategic Leadership of Change in Higher- Education, Routledge, Oxon, 2007.
- McMasters, John H.; Komerath, Narayanan; Boeing – University Relations; A Review and Prospects for the Future; Proceedings of the 2005 American Society for Engineering Education Annual Conference & Exposition; Portland 12-15 June 2005.
- Meijers, A.W.M. ; Overveld, C.W.A.M.; Perrenet J.C.; Criteria for Academic Bachelor's and Master's Curricula, joint publication of TU Delft, TU Eindhoven, University Twente, 2005. Retrieved 28 August 2014 from [https://www.utwente.nl/majorminor/info\\_algemeen/criteria\\_for\\_curricula.pdf](https://www.utwente.nl/majorminor/info_algemeen/criteria_for_curricula.pdf).
- Meijers, A.; Brok, P. den; Engineers for the future: an essay on education at TU/e in 2030. Eindhoven University of Technology; Eindhoven, 2013.
- Meyers, Carolyn; Restructuring Engineering Education: A Focus on Change; Report of an NSF Workshop on Engineering Education, National Science Foundation, Arlington, April 1995.
- Menken, S.B.J.; Keestra, M.; An Introduction to Interdisciplinary Research (pilot version), University of Amsterdam, Institute for Interdisciplinary Studies, Amsterdam, 2014.
- Mourshed, Mona; Farrel, Diana; Barton, Dominique; Education to Employment, Designing a System that Works; McKinsey Center for Government, 2013, retrieved 22 August 2014 from <http://mckinseyon-society.com/education-to-employment/report>.
- Polczynski, Mark; Jaskolski, Stanley; Entrepreneurial Engineering Education; NCIIA 9th Annual Meeting; San Diego, 2005.



Robinson, David W.; Academic Space Engineering Competence and Skills Requirements Study; Psi-tran Ltd, Sunbury on Thames, October 2013.  
Robinson, Ken; Out of Our Minds: Learning to be Creative; Capstone, West-Sussex, 2011.

Roo, Mieke de; Gorp, Tonja van; Interdisciplinary Learning Activities; University of Amsterdam, Institute for Interdisciplinary Studies, Amsterdam, 2014.

Royal Academy of Engineering; Educating Engineers for the 21st Century; The Royal Academy of Engineering, 2007; retrieved September 11, 2013 from <http://www.raeng.org.uk/publications/reports/educating-engineers-21st-century>.

Sahlberg Pasi; Finnish Lessons, Teachers College Press, New York, 2011.

Spinks, Nigel, Silburn; Nick; Birchall, David; Educating Engineers for the 21<sup>st</sup> Century: The Industry View; The Royal Academy of Engineering, 2006; retrieved July 12, 2013 from <http://www.raeng.org.uk/publications/reports/educating-engineers-for-the-21st-century>.

Sutton, Adrian; Imperial Horizons, Creating Leaders in Science and Engineering, Imperial College, London, 2011.

Wagner, Tony; The Global Achievement Gap, Basic Books, New York, 2009.

Wagner, Tony; Creating Innovators, The Making of Young People who will Change the World, Scribner, New York, 2012.

## Workshops and Conferences

Panel discussion “Tomorrow’s engineers – for an attractive Europe: Working Together to Build on Europe’s Excellence in Engineering Education and Research”; 4th European Convention for Engineering Deans; Birmingham, 29-30 March 2012.

Workshop on Education and Training for the Future Generation of Aviation Professionals in Europe, Brussels, 7 June 2012.

Workshop on the “Vision on engineering education”; Directors of Education TU Delft; Delft 23 May 2013.

Panel discussion “Closing the gap between University and Industry”; International Symposium on Project Approaches in Engineering Education; Eindhoven, 9 July 2013.

Workshop on Space Engineering Competences and Academic Education, CEAS 2013 Air and Space Conference; Linköping, 17 September 2013.

Workshop “Imagineering, The Engineer of the Future”, ORAS, Delft, 28 March, 2014.

## *Bibliography*

Workshop on the NOTIS project;  
Science and Technology in the Society;  
KTH visit to Delft, 23 May 2014.

Workshop on Education and Training  
Needs for Aviation Engineers and  
Researchers in Europe, Brussels, 13 June  
2014, retrieved 14 July 2014 from [http://  
www.acare4europe.org/documents/work-  
shop-education-and-training-needs-avia-  
tion-engineers-and-researchers-europe-0](http://www.acare4europe.org/documents/workshop-education-and-training-needs-aviation-engineers-and-researchers-europe-0).

Workshop “The Engineer of the Future,  
Company Strategy and Competence  
Priorities”, Airbus Group University  
Partner Event, London 16-18 July 2014.

CDIO Global and Regional meetings:  
Copenhagen, June 2011; Palo Alto,  
October 2011; Brisbane June 2012;  
Boston June 2013; Gothenburg,  
January 2014; Barcelona, June 2014.