TU/e VISION ON EDUCATION

TU/e
EINDHOVEN UNIVERSITY OF TECHNOLOGY

COLOPHON

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Executive Summary

The TU/e Vision on Education is an elaboration on the vision presented in the Strategy 2030 and describes the direction TU/e envisions for future education. This document is an elaboration of the vision on education that is presented in the Strategy 2030[1] and builds on the vision on education that was published in 2013[2] and the vision of the deans from 2019, which served as a guideline for shaping Bachelor College 2.0. The vision is based on our mission to

1) educate responsible engineers of the future who are prepared to take on important societal, technical and scientific challenges; and
2) offer high-quality education that is authentic, flexible and can be adapted and improved to meet the challenges of a quickly changing world.

The vision text is organized around three core questions:

1. **who do we educate,**
2. **how do we educate them and**
3. **in what context?**

Who do we educate? At the core of our vision is the TU/e engineer for the future. They have a T or π-shaped profile, combining rigorous disciplinary knowledge, academic thinking and expertise with a general level of understanding and skills that enables them to work and communicate with colleagues from other disciplines in a diverse environment. They are self-aware, can reflect on their learning, have the skills and mindset for life-long learning and development, and can contribute in a meaningful way to the societal and technical challenges that lie ahead of us. To educate the engineers for the future that society needs to solve the challenges that we are faced with, we want to offer an inclusive and accessible learning environment that enables an increasingly diverse group of learners to become those engineers for the future.

How do we educate the engineers for the future? The following three characteristics form the basis of future TU/e education:

1. **Learning in a flexible hybrid system to facilitate diverse learning paths;**
2. **An authentic, integrative, and activating educational concept: Challenge Based Learning; and**
3. **Self-directed learning that acknowledges personal development and professional identity.**

They encompass a way of learning in which our campus is an important place for highly interactive and small-scale education combined with optimal use of digital tools. Important enablers for this are among others digital innovations that enable data-supported education and well-organized support for teachers and students. The context in which our education takes place is formed by the TU/e ecosystem. For our academic and professional staff team teaching, teacher professionalization and a system of recognition and reward that values education and innovation are essential. Our teaching staff is essential in realizing innovation, and well-organized support should help reduce their workload. Research and education are very much intertwined and strengthen and enrich each other. In both, great importance is placed on the theme of sustainability, as defined in the UN Sustainable Development Goals. The campus infrastructure should be organized in a way that enables the envisioned education. But our ecosystem goes beyond our campus

and includes the valuable collaborations we have with industry and with our national and international alliances of educational partners. Further strengthening and developing these collaborations will support us in developing in the direction described in this vision.

Developing towards the direction sketched in this vision will make us more resilient to disruptive changes in the world around us, such as the ones we have seen in the last few years. It will require us, just like our students, to constantly learn, reflect and develop. Many initiatives, programs and projects are already in place or in development to discover and study the innovations that suit TU/e best, for example with important topics such as CBL and digital innovations. As we learn together as an organization and experience new ways of working, the ideas that are outlined in this text will mature and take shape. The strengths and innovativeness of the TU/e community will help us to achieve a way of educating that suits our institution and enables us to educate the TU/e engineers for the future.

1 - TU/e (2018) Strategy 2030: Drivers of change. Eindhoven: TU/e.
2 - Meijers & den Brok (2013) Engineers for the future.
An essay on education at TU/e in 2030. Eindhoven: TU/e.

Engineers for the future, with a lifelong learning mindset

Employability is more than finding a job, it is about developing your professional identity

Preface

Before you lies the TU/e vision on future education. This document is an elaboration of the vision on education that is presented in the Strategy 2030[3] and builds on the vision on education that was published in 2013[4] and the vision of the deans from 2019, which served as a guideline for shaping Bachelor College 2.0. In the (COVID-induced) extensive time from first ideas through to the current text, this vision has been discussed with many stakeholders in the university. We would like to thank the numerous people that were involved in some way in this process for the enriching discussions and useful insights that have helped shape the current text.

The vision text is intended and should be read as a "dot on the horizon". It describes the direction we envision for TU/e education in the future and should be seen as compass that guides and directs our steps for the coming years. The dot on the horizon is rather broad and hazy, and the contour is not yet defined. In the coming years, the picture will become sharper as we learn from our experiences and collectively give meaning to the concepts and directions of the vision. The ideas that are outlined in the text will mature over time as we experience new ways of working and discover what works best for our institution. With this compass in our hands, we embark on a journey together to shape TU/e education in a way that enables us to educate the engineers for the future.

3 - TU/e (2018) Strategy 2030: Drivers of change. Eindhoven: TU/e.
4 - Meijers & den Brok (2013) Engineers for the future. An essay on education at TU/e in 2030. Eindhoven: TU/e.

Introduction: Future TU/e education

The last few years have demonstrated that large challenges present themselves to us in areas such as sustainability, while sudden changes such as a world-wide pandemic require us to be resilient and flexible. Technology is becoming ubiquitous, highly complex, and has permeated all areas of our lives. Societal, technical and scientific challenges require engineers who have a deep understanding of their discipline, know how to keep up to date, and are able to work on complex systems in multidisciplinary settings and multicultural teams. Future TU/e education will prepare them for all of this. To become engineers for the future, students learn to take responsibility of their own learning path now and in the future. The TU/e campus offers a lively and inspiring community where students experience a personal and small scale environment in which they can complete their chosen trajectory in a flexible way. Learning on campus is highly interactive and focuses on addressing relevant societal and technical challenges in multi-disciplinary teams and in cooperation with industry and other stakeholders in society.TU/e education provides students with a real-life engineering context and is designed to highly engage them by creating an intrinsic need for acquiring and applying rigorous knowledge. An aligned array of knowledge modules allows students to learn the key concepts and theories they need. To enhance flexibility, these modules can be offered on-campus and online, using the latest ICT innovations to enable just-in-time interaction and feedback. In addition to knowledge, students develop the skills and attitude they need to face the challenges of the future. The academic teachers design and develop innovative learning activities and environments and are able to shift effortlessly between their different roles: sometimes they offer knowledge by being the "sage on the stage", but frequently they coach students in their development towards engineer of the future by being the "guide on the side".

This is what we currently envision the future to look like, based on the developments that are taking place in the world and on our campus. The coming years will have to prove whether this image will indeed have taken a clearer shape. We do, however, already see proof of how powerful this way of learning can be in our student teams. They demonstrate the innovative strength of students, their commitment to solving societal and industrial challenges and the amazing results that are possible when they collaborate in students team up to work on societally relevant challenges using the latest technological and scientific information. TU/e will take a next big step towards innovation of the way in which learning takes place to offer all students the opportunity to experience this way of learning. Educational innovation will also enable a strengthening of the link between education, research and industry, providing the opportunity to acquire rigorous knowledge in an authentic learning environment.

In this document, we describe why and how we expect education at TU/e to develop and change in the coming years. We need to be flexible and agile to adapt to the changing circumstances and possibly disruptive changes that will take place in education worldwide, and to the learning needs and personal interests of our independent learners. The COVID-19 pandemic has demonstrated how quickly circumstances can change, and how resilient we need to be. At the same time, we want to safeguard the strengths of the TU/e, which can be used as a starting point to meet the challenges and changes that face us. This vision is intended to guide our course towards the future, as a compass to point us towards the envisioned direction and to help us make long-term decisions.

Drivers of change

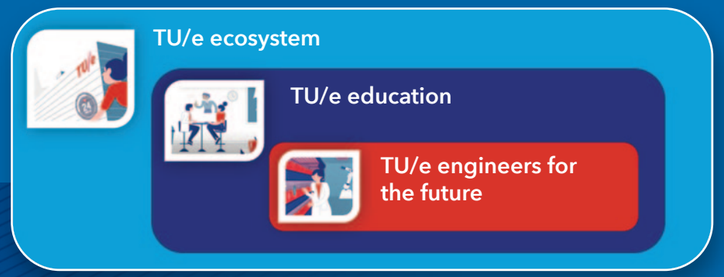
The TU/e Strategy 2030 (2018) describes the drivers of change that will affect the field of engineering in the coming years. The period between now and 2030 will bring about many societal changes and technological challenges which will also have an effect on engineering education. Society faces sustainability challenges that are clearly reflected in the UN Sustainabile Development Goals, which require cutting-edge technological innovations to shape future solutions. Our students will be the future engineers who help to tackle these challenges, and education at TU/e and its ecosystem should prepare them for this. Societal and technological challenges will give our future students a purpose and will impact their motivation to choose, plan and complete a certain learning path. The field of work is changing on a large scale and is characterized by the ubiquitous presence and fusion of technologies. This will bring about changes in the way students (expect) to learn, and also in the expectations that the work field will have of our graduates. Students will need to learn how they can function and thrive in a world and work field that is ever-changing and transforming[5], to be prepared for future jobs that may not even exist yet at this moment. Engineering and education are transforming, and TU/e education needs to keep developing to meet the needs of the world around us.Our mission for TU/e education of the future is to:

- Educate responsible engineers of the future who are prepared to take on important societal, technical and scientific challenges
- Offer high-quality education that is authentic, flexible and can be adapted and improved to meet the challenges of a quickly changing world

5 - Hannon, V. & Peterson, A.(2017). Thrive: schools reinvented for the real challenges we face. Innovation Unit Press.

Real-world, open ended challenges

TU/e education



Large and potentially disrupting changes in the engineering profession and education drive TU/e to be agile and take significant steps in the development of its education. Below we delineate and define the direction we expect this development to take for our students, faculty, institution and ecosystem, and how we can work together towards taking this next big step in our development.

TU/e learners and graduates

TU/e engineers

TU/e students will graduate as responsible engineers, who have the rigorous knowledge, attitude and skills to find their way in the constantly changing world, who critically analyze the wealth of information available to them, and who are aware of the impact of their work. They truly will be the engineers for the future, who have a T or π-shaped profile, combining (deep) disciplinary knowledge and expertise with a general level of understanding and skills that enables them to work and communicate with colleagues from other disciplines in a diverse environment. They are critical thinkers who can reflect on their learning, have the skills and mindset for life-long learning and development, and can contribute in a meaningful way to the societal and technical challenges that lie ahead of us. TU/e engineers have a thorough knowledge of their field of work and how this relates to other disciplines in the field of engineering, and are self-directed learners with an entrepreneurial mindset and a clear professional identity. They have the knowledge, skills and proactive attitude to take on complex multidisciplinary challenges, and have experienced what it is like to do so. Being adaptable self-directed learners, they are resilient and can identify their learning needs and develop learning strategies that allow them to keep up with any new development in the field of work and continue to shape their engineering profile in a way that suits them best. The way we look at and measure student success will be guided by the characteristics of these TU/e engineers for the future.

The TU/e engineers will shape their own learning path and so create their unique professional identity. A TU/e education will help prepare them for the next step in their lives and careers and equip them with the right skills and attitude to continue their development.

Diverse learners

To educate these engineers, TU/e offers learners an **inclusive and accessible learning environment**, which is known to enhance learning and performance[6], while supporting their well-being. Diversity enriches the community and the learning process, enhances creativeness and innovation, and helps prepare students for the reality of their future working environment. TU/e is an inclusive community that appreciates the diversity of its students, faculty and ecosystem. TU/e will have a (super)diverse campus with people differing in many areas, such as sociocultural background, ethnicity, gender, sexual orientation, religion and health. They will also differ in their drive for learning, ambitions, and motivation to choose a certain discipline, degree program or learning pathway. From an intersectional perspective, we appreciate the uniqueness of each individual and acknowledge how we differ but also what we have in common. We expect and encourage diversity to grow and want to offer all students and faculty an inclusive community that respects, appreciates and fosters diversity, and a learning environment that helps all students to take ownership of their development and shape their own personalized learning path. This means that it will be easier for students with various backgrounds, circumstances and learner needs to find their way at TU/e and develop their talents. However, **diversity alone does not guarantee inclusivity**. To achieve a truly inclusive environment, it is important to be aware of any biases or roadblocks that may hinder inclusivity and accessibility, and make sure that these are addressed so that each student feels at home at TU/e and has the opportunity to achieve their full potential. The environment should be equally inclusive for our lecturers, with a bias-free evaluation of their performance and appreciation for all aspects of their work (education, research, impact and academic citizenship/leadership).

The diverse atmosphere of the future field of work of our students is reflected in the **inclusive engineering** education at TU/e. Communication is facilitated by the fact that TU/e has chosen English as its “lingua franca”, which enables exchange in the international classroom. However, to have a truly inclusive classroom, more is required than just sharing a language or having diverse teams. The inclusive classroom at TU/e is seen as an asset and enrichment, offering students and staff a more diverse perspective on their disciplines, and insight into inclusive collaboration. TU/e wants to ensure that this enrichment is used to its full potential. We strive towards a balanced mix of students in our population to enhance exchange and collaboration, and our staff is aware of differences, also with respect to how people learn. TU/e will support them with the knowledge and tools required to make sure that we take full benefit of the enriching characteristics of the inclusive classroom. Learning goals concerning the inclusive classroom will be a more explicit part of TU/e learning experiences and outcomes. Students will learn how to flourish in an inclusive work environment and develop their talents to achieve their ambitions.

TU/e offers education for **learners in different stages of their development**. Bachelor, Master and post-graduate education (both EngD and PhD) are aligned with each other to offer a comprehensive learning path with increasing complexity, specialization and competence development, but can also be entered by external learners at different points. We foster an attitude of Life-long learning and development in our students and have opportunities for them and others to continue to do so at our institution.

6 - Ambrose et al (2010) How learning works. San Francisco, CA: Jossey-Bass.

Students gain a network of connected disciplinary knowledge and skills in a multidisciplinary context.

TU/e education – Developing from teaching to learning

The changes in higher education such as the impact of technology and the omnipresent availability of information will have a strong impact on both the motivation and purpose of our future students, and on the way in which learning takes place. TU/e has proven to be an agile organization that can adapt to changes and implement large-scale educational reform. The introduction of first the Bachelor College and then the Graduate School were important steps towards giving students more freedom in shaping their profile, and student evaluations demonstrate that this is one of the elements that draws them towards TU/e. To meet the challenges and changes that we see happening in the world, and changes in education that come our way, the vision described here is a logical step in our development towards an education system in which student learning will take center stage.

The emphasis within learning at TU/e will shift towards learning activities based on real-life questions and challenges, resulting in a much more diverse and truly supportive learning environment that offers students many different ways to acquire and apply the knowledge, skills and attitude they need. Learning takes place in numerous different environments, both by individual students and by (multidisciplinary) groups. Contextualized learning will be more prominent, where rigorous academic knowledge and skills are acquired and applied in the authentic contexts in which students need them, for example in collaboration with our unique Brainport ecosystem. Working on challenges in (multidisciplinary) teams implies a shift from competitive and individual learning, in which students work individually and in competition with each other to score the best grade, towards collaborative learning: discovering the knowledge and skills needed to solve challenges together, and learning how each discipline contributes to this cycle and that the interplay of various disciplines creates solutions that cannot be achieved by one single discipline. This reflects the way professionals function, and will prepare students for the engineering profession, while self-directed learning will equip them with the skills to adjust to changes and to jobs that currently don't exist yet. TU/e will offer its students meaningful learning experiences that engage them, allow them to develop cognitively and emotionally, and enable them to reflect on their own learning and development.

Therefore, future TU/e education will have the following characteristics:

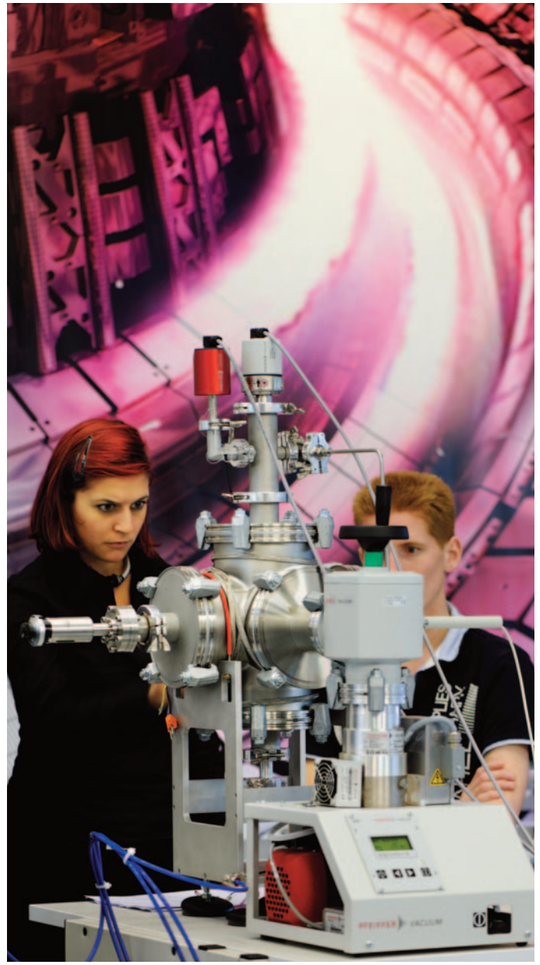
1. **Learning in a flexible hybrid system to facilitate diverse learning paths**
2. **An authentic, integrative and activating educational concept: Challenge Based Learning**
3. **Self-directed learning that acknowledges personal development and professional identity**

These elements, and how we can enable them, will be explained on the next pages.

1. Learning in a flexible hybrid system to facilitate diverse learning paths

The TU/e engineers for the future have **rigorous knowledge** of their discipline. When we speak of rigorous knowledge, we mean a **deep and thorough understanding of the key concepts of their discipline**. This is (much) more than knowing the state-of-the-art theories, it also entails a certain level and way of thinking, and the appropriate strategies to stay up to date in quickly developing disciplines. TU/e offers students a learning environment that allows them to develop their expertise. Meaningful learning experiences are designed in a way that invites students to seek deep understanding and build up a network of key concepts and theories that grows throughout their program. TU/e students acquire knowledge in the relevant context, working on authentic questions.

While the knowledge is rigorous, the way in which it is taught is flexible. Becoming a TU/e engineer will be possible in a personalized and flexible way to meet the needs of different learners. Authentic learning and diversity of learners ask for a **flexible hybrid system of making knowledge available** (online and offline, synchronous and asynchronous). A seamless blend of on-campus and digital education allows students to study in a way that suits their characteristics and their learning path. In a time where digitalization in learning has taken flight, we certainly see an essential role for **on-campus learning**. The vibrant and diverse community on our campus is an inspirational environment where students and staff can meet, study, collaborate and work on challenges. Education taking place on campus should



be focused on exactly that: meaningful interaction and active learning. To support this way of learning, knowledge is offered in a flexible way, making use of the **latest developments in digitization of education**. In that way, both students and faculty have all the tools at their disposal to organize learning in a truly flexible way, enhancing the autonomy of staff and their freedom to shape education in a way that suits them. To enable this, we will make use of the latest ICT innovations to offer a supportive platform for educational innovation. State-of-the-art data-supported IT-platforms and facilities are necessary to support students and teachers in the different learning activities and innovations. Development of existing and new tools to come to a high-quality hybrid learning infrastructure will allow for easier collaboration and communication among students and between students, lecturers and our (Brainport) eco-system, both on and off campus.

For the development of the curriculum, it will be important to strike the right balance between offering solid fundamental engineering knowledge and providing optimal flexibility. An important condition for this is the flexible and **"just-in-time" availability of information**. While we still expect that many students will follow the curriculum as it is designed, digital tools can help us achieve flexibility, removing the restrictions of time and place. Offering the material in modules that cover clearly delineated topics will further enhance this, while these modules can also be easily incorporated in different learning lines. While it is often suggested that in the engineering field the order of presenting information is essential, literature demonstrates that expert knowledge is built around key concepts, and modules can help students in developing a network of knowledge[7].

Students need to be able to organize their knowledge around these key concepts and principles in order to gain expertise and transfer their knowledge and skills to novel problems. This allows for more flexibility in the curriculum. A flexible system has multiple advantages over the more classic system in which the order of the courses is essential and often completely fixed. From a learner's point of view, the agile system offers efficiency and effectiveness, and optimizes learning for students with various learner needs. It promotes self-directed learning and an independent attitude in students, and the retention of the information is likely to be much higher if they are able to apply it right away. Placing information in context will facilitate insight into the links and relations between different areas of engineering.

Working on the challenges, and acquiring the knowledge and skills necessary for them, will allow the student to build up a network of connected disciplinary knowledge and skills in a multidisciplinary context.

TU/e curricula are well-designed learning paths that are suitable for a substantial part of our student population. For students who want and/or need to set their own course, TU/e offers the opportunity to have **diverse and personalized learning paths**. Self-directed, flexible learning requires us to trust that the students are able to (learn to) reflect on their learning and development and shape their own learning trajectories. In addition to giving them the flexibility and choices to do so, they are provided with guidance in making choices that fit their needs and wishes. The students will need to develop the ability to assess their own progress and learning needs, and how they can shape their learning trajectory to meet those needs. They will develop these capabilities as they go through the different stages of their study program, and the way they are guided will be a reflection of this development. Their independency will increase as they move through bachelor, master and EngD and/or PhD. Student ownership of their trajectory and the partnership between student and staff are important and will change according to the stage of the program.

In this, we constantly strive to optimally combine the strength and support offered by the community and a cohort of peers with the flexibility of personalized learning paths. The engineering and didactic expertise of the staff is essential in supporting student learning. It will enable them to design modular and challenge-based education, and coach and guide the students in their development and safeguard that the path they choose is a meaningful learning pathway that can lead them to the engineering degree and profile they are working towards. This means that the curriculum is reviewed to identify the key concept and general principles that are currently discussed together in courses, and that this is used as a basis to make the transfer from larger course structures to smaller modules which can be embedded in meaningful learning pathways. Hybrid learning can be used to make them available to students year-round and in different ways. Teachers and students can **blend the different learning activities, both synchronous and asynchronous**, in a meaningful way that suits the learning objectives of the activity and the learning goals and needs of the student and promotes active and interactive learning, both individual and in teams. The design and organization of blended education should optimize the development of independent learning by students. To achieve all this, lecturers can rely on a good pedagogical support system. Combined, these developments will make it possible for students to shape and follow a personalized learning path.

Personalized learning paths need to be accompanied by a suitable way of **assessing, ideally as an integrated part of learning**. Assessments[8] can act as a guide to inform the student of their level of mastery of certain subjects and whether they have acquired the rigorous body of knowledge, skills, and attitudes needed to continue their academic trajectory. Such assessments for learning and assessments as learning thus stimulate and enable self-directed learning and increase students' self-efficacy. It is imperative that these assessments provide meaningful feedback to students and preferably are

delivered in multiple measurement points to allow for targeted growth and a more uniforme distribution of study load. In order to serve both purposes, the assessment plans of the programs at TU/e should ensure there is a balance between assessments of, for, and as learning. To shape assessment at TU/e, four leading principles for assessment have been identified:

1. empowering students towards self-directed learning by providing assessment as learning through abundant measurements moments that track and report the students progress in their individual learning objectives, encouraging students to reflect on their development and to identify the next steps in their learning proces.

2. involving multiple stakeholders in assessment providing different perspectives in multidisciplinary settings, and making the assessment adaptable to each student's needs and personal learning goals.

3. assessing students on individual learning objectives enabling flexible and personalized learning trajectories by offering time-independent and location-independent assessment.

4. ensuring the development of just-in-time knowledge by designing assessment on program level to enable authenticity in and alignment between the different elements of study components and corresponding assessments.

More personalized and diverse learning trajectories will lead to greater diversity, but a **TU/e degree certificate will remain a solid guarantee** that the student has gained the knowledge and field-specific and generic skills to function as an engineer of the future. A more flexible system also incorporates the option to acquire knowledge outside of the TU/e, for example within the alliances that TU/e is part of. However, TU/e will only give students a degree if the appropriate level is reached. The exam committees have an important role in assuring that that the learning path chosen is right for the student and the required level is indeed met by graduating students. A more flexible system, and the experiments that will be conducted during the development of our education, will become feasible if we combine a solid quality check with a flexible attitude and approach in the area of assessments and degrees.

The way in which the field of work regards and treats degrees may change in the coming years as new developments arise[9]. Changes are already visible as microcredentials, badges and other systems become more prevalent, and could in some cases even become a replacement for a degree in the future. The agility and flexibility of TU/e will allow us to adapt to these changes while maintaining the quality that the field of work knows and expects from us.

7 - Litzinger, T., Lattuca, L. R., Hadgraft, R., & Newstetter, W. (2011). Engineering education and the development of expertise. *Journal of Engineering Education, 100*(1), 123-150.

8 - The term assessment refers to the wide variety of methods or tools that educators use to evaluate, measure, and document the academic readiness, learning progress, skill acquisition, or educational needs of students.

9 - See: Fong, J., Janzow, P., & Peck, K. (2016). Demographic shifts in educational demand and the rise of alternative credentials. Retrieved from: https://upcea.edu/wp-content/uploads/2017/05/Demographic-Shifts-in-Educational-Demand-and-the-Rise-of-Alternative-Credentials.pdf and Deming, D. J., Lovenheim, M., & Patterson, R. (2018). The competitive effects of online education. In Productivity in Higher Education. University of Chicago Press.

"I never teach my pupils, I only attempt to provide the conditions in which they can learn." *Albert Einstein*

2. An authentic, integrative and activating educational concept: Challenge Based Learning

The changes in the characteristics and drives of our students, the changing demands of the work-field, combined with information becoming more and more widely and digitally available, will bring about large changes in the way that learning takes place. In addition to a flexible system of gaining knowledge, TU/e wants to provide students with a rich on-campus learning environment that is **authentic** and **activates** students by creating curiosity and learning urgency and stimulating collaboration. In order for deep and meaningful learning to take place, students need to be able to **integrate and apply knowledge and skills to solve real-world problems**[10]. Learning how to do this in partnership with capable academic staff will be a key element that distinguishes universities from online information sources. The educational concept of Challenge Based Learning (CBL) can help us to achieve this type of learning at TU/e in the future. TU/e sees **CBL as an integrative educational concept, a coherent way of offering the opportunity to gain knowledge, skills and the attitude required for the engineering profession**. CBL as a curriculum design concept can help us shape curricula where different types of learning activities are combined in a way that promotes integration and deep learning. CBL is a concept that should be seen on a curricular level, it goes far beyond working on projects and can encompass all different types of learning activities that contribute to the active and integrated way of learning we envision. In a **well-designed CBL curriculum, meaningful learning paths based on authentic challenges and deep knowledge will take shape. In an authentic context provided by challenges, existing knowledge and skills are connected and applied, while new knowledge and skills are gained**.

Ample research[11] demonstrates that active learning based on real-life challenges poses many advantages over classic lecture-based teaching, and will help us develop from teaching to learning. Self-directed and contextualized learning combined with reflection on learning lead to a deeper level of understanding. Contextualized learning facilitates the transfer of knowledge and skills to other challenges and areas, preparing students for their future career. Learning in (multidisciplinary) teams allows students to take ownership and gain skills that are deemed essential by their future employers. CBL can help develop systems thinking, which will be essential for engineers that enter the job market to work with increasingly complex systems. CBL is aimed at creating drive and enthusiasm among students, as they are able to do innovative work on highly relevant societal and technical challenges. The experiences in the TU/e Honors Academy, in the student teams and with education taking place in TU/e innovation Space certainly demonstrate this. Numerous success stories can serve as examples: teams like teams like Solar Team Eindhoven, Solid, Tech United, SensUs and URE have done innovative work in a very diverse range of areas, and have seen world-wide appreciation for and acknowledgement of their work. The collaboration between students and scientific staff in these teams provides a clear link between research and education.

These developments do not happen at TU/e in isolation, they are part of a word-wide development taking place. Ruth Graham[12] predicts that the field of engineering education will face large changes in the coming years. In several other universities around the world, we see comparable developments taking place, for example at the University of Monterey. According to Sheppard (2009) a possible pitfall is that changes in (engineering) education are mostly made at the course level, or as an extracurricular element. This may only confuse students, as different parts of their curriculum demand different attitudes from them with regard to ownership and self-regulation for example. To really have the optimal effect and a coherent whole, an integrated approach on the curriculum level is needed, with integration and scaffolding of CBL characteristics in the educational components (including theoretical courses) throughout the curriculum. What exactly do we envision when we talk about CBL? Several definitions exist in literature[13], of which we have distilled a number of components to be possible characteristics of CBL at TU/e:

- **CBL places relevant real-life open-ended challenges at the basis of learning**

These challenges can come from very diverse sources (research, industry, society), but they have in common that they are able to engage the students by being societally relevant, technically challenging and relevant for the engineering profession. By giving these types of challenges a central role in our education, students see and experience right away what they are learning, what the purpose is, and how this will enable them to contribute to the solution of important societal topics.

These types of challenges create learning urgency in the students and enable them to apply the knowledge they gain.

CBL leads to active learning

Learning is an active process by nature, and learning activities should be designed to promote an active attitude in students, allowing them to construct a network of knowledge and take ownership of their own learning process. In a CBL-based curriculum, all components are designed to invoke this active attitude. Posing a real-life challenge activates and motivates students to engage in the process. Accomplishing a result that actually makes a difference is what counts for students, and it will drive them to take the lead. CBL requires this active attitude and approach from students, they need to take ownership in order to accomplish the desired result. As a group, they are responsible for achieving a result that makes a difference, in which each student has a unique contribution and takes a deep learning approach.

CBL helps to develop system thinking

In order to become engineers that are able to cooperate within a diversity of disciplines, and solve challenges in complex systems, students need a deep understanding of the field in which they are specializing and the ability to take a broader view so they appreciate and value ways of thinking different from their own. This will truly make them T or π-shaped TU/e engineers, who have deep disciplinary knowledge and the ability to work in a multidisciplinary environment, where the expertise of many disciplines is connected and integrated to solve complex problems. System thinking is an essential part of this, and applying and gaining knowledge and skills while working on complex real-life challenges will help students to develop system thinking.

CBL helps students to learn how to work in an iterative cyclical way

By working on real-life challenges, students experience the different stages of the iterative cycle of analysis and synthesis, and hypothesizing and experimenting. They can analyze complex questions and challenges and approach them in a scientific way. They practice divergent reasoning to develop creative and innovative solutions, and convergent reasoning to analyze these options and assess which one is most desirable, feasible, and viable. Both ways of reasoning are essential for engineers.

Students learn to tackle challenges of all sizes

CBL invites students to acquire knowledge “just-in-time“

CBL creates a learning urgency for students: in a CBL-based curriculum they will learn to see that solving the challenge will require the acquisition and application of new knowledge and skills (for example in theoretical modules or courses taken in parallel with a CBL project). The information material and learning activities they need for this, will be different for each student, and will need to be divided into small units that are easily accessible to them. It would be very strange if they could continue working on their challenge only after taking a course that is scheduled in six months’ time. Learning “just-in-time“ also implies that the knowledge and skills gained are applied immediately in context and can easily be connected to prior knowledge. This facilitates contextual learning, enhances deep learning and optimizes the retention of information.

CBL involves science, industry and the societal context

The challenges in CBL can be designed based on questions from (fundamental and applied) research, from industry and from society. Knowing the importance of the challenges in these contexts, will give solving them urgency and meaning, motivating the students. It also allows them to see what working in these different settings is like, enabling them to make more informed and balanced choices for their future career.

CBL helps students to learn to work in a multidisciplinary team

The real-life challenges will often need a multidisciplinary approach, and therefore will allow the students to practice working in a multidisciplinary team, where all team members contribute from their own expertise and skills, and learn to work together to achieve the desired result. This will offer learning opportunities to enhance their skills with regard to team-work, project management, communication across disciplines and cultures, and leadership. It will help students appreciate the role of the different disciplines, and see their own discipline from new perspectives. They will experience that the outcome of a project is more than just the sum of the disciplines.

CBL includes reflection on the learning process and development of students

To fully use the potential learning experiences of CBL, and come to deeper learning, students need to develop their meta-cognitive skills and self-regulatory abilities. This can be done by including the opportunity for students to reflect on the quality of the outcomes and

on their learning strategies, progress, and development in learning activities, which in turn support the development of critical and academic thinking. They will learn to assess their own level of development and learning needs, and which strategies are best suited to enhance their learning. A growth mindset will be created, allowing them to use the learning opportunities in CBL to their fullest.

These characteristics can help us in developing CBL-based education, giving shape to how students can grow and develop throughout their program by building up complexity and responsibility in CBL. They can also help the different programs in developing a CBL-based curriculum that optimally fits with their discipline. A compass tool was designed to assist in this process[14].

A CBL-oriented curriculum requires a larger systemic change with different elements (knowledge modules, courses, challenges etc) redesigned and developed in parallel. A key role in CBL is reserved for the staff. The design of challenges that motivate students and enable them to learn is essential for its success. Academic teachers will design learning experiences, which will combine all the different elements of CBL to reach the full benefits it has to offer. They will guide the students during the challenges, will help them in finding and understanding the knowledge and resources they need to take on the challenge, coach the teams during the challenge and will assess their progress. The open-ended nature of the challenges will make the staff and students partners in learning, and staff can be a role-model for students in this process. They will also present themselves as learners, and show that engineers are constantly learning and developing throughout their career. This is a much more complex and diverse teaching role than solely giving lectures, and will demand more diverse didactic skills and a flexible and open attitude. To enable and stimulate innovation, while managing workload, **TU/e will support its staff** in these different roles by providing comprehensive **tools and knowledge** on CBL and by organizing an **extensive support system**. Organizing education in cross-functional teaching teams that combine different roles and expertise will facilitate the change. Additionally, the shift from a more classic curriculum to a CBL-based one, will require information to be accessible at all time to students in small units and a flexible system. ICT innovations with regards to study and student management are necessary to help us achieve this.

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3. Self-directed learning that acknowledges personal development and professional identity

TU/e supports students in becoming self-directed learners, students are stimulated to **take ownership of their learning and development**. They learn to reflect on their development and, based on this, seek the knowledge and skills they need, and critically appraise the information they find. In doing this, a **growth mindset** is essential. The focus of boths students and the teachers that guide them should be on the potential for development, and on how the educational program can help to optimize development. A growth mindset implies that we place the emphasis on the *development* of competences and less on the actual level achieved. Shaping their own study path will help to create a **mindset of life-long learning** among students because during their time at TU/e, they learn to assess their own development, learning preferences and learning needs. This will help them to complete their learning trajectory at TU/e, but it will also make them aware that learning never stops, and that they can apply the learning strategies and preferences they gained at TU/e throughout their professional career.

Students in the lead of their learning does not mean that they are left to their own devices, TU/e wants to support, guide and advice them throughout this process, and **challenge them to make the most of their potential**. This means that students should have a clear overview of the elements that are available to them to shape their learning path and support their development, both within and outside the curriculum. However, this alone

will not be enough to help them take the lead. They need to reflect on their learning and development, and this means that they have **coaching and high-quality feedback** to guide them in this process. It also means that there should be a **rich digital learning environment**. **Learning analytics** can be used to give insight to the students on how they are progressing, and it can help the university to keep track of how students are acquiring the knowledge and skills they need.

In addition to a deep understanding of their discipline, and gaining relevant field-specific skills and an academic attitude, TU/e students are also prepared for the future by the **development towards a clear professional identity**. They will practice problem analysis and solving, creativity, and critical thinking and will develop an innovative and entrepreneurial mindset. This will help the students achieve sustainable employability. Employability in the TU/e curriculum goes beyond career readiness; it entails knowing who you are as a person, engineer and team-member and shaping a career path that matches your profile, personality and drive. When TU/e students enter the job market, they have had the opportunity to develop a clear professional profile: **they are aware of their strengths and weaknesses, know who they are as an engineer and know how to develop themselves to shape their own future**. To achieve this, students are aided throughout their study career in multiple ways: they are brought into contact with the different fields of work that are available to them after graduation, their skills are honed to match the demands of their future employers, they are prepared for their future work in CBL, and they are given the opportunity to reflect on their capabilities and interests, and on what drives and motivates them. **Coaching** is provided as an integral part of their learning throughout the different stages of their education to help them reflect on their learning and development, and in shaping their professional identity. Students will be guided as they reflect on their learning, choose their learning path, work in teams, develop their skills, and explore and experience what the fields of work look like. The content, method and intensity of the coaching will change in the different stages of education, as will the coaching roles. Coaching and mentoring in the postgraduate EngD and PhD trajectories will have the most intensive and personal character.

For TU/e students, **lifelong learning** commences at the start of their bachelor education, they will learn how to learn, and gain both the skills and the attitude that are prerequisites for lifelong learning. They learn to reflect on their learning process and outcomes, and the development of their knowledge and skills, and are able to determine their learning needs and the strategies that suit them.

Each student who graduates from TU/e has had the opportunity throughout their study career to reflect on the multiple profiles of engineers, and on the avenues available to them after graduation. The diverse nature of the challenges will bring them into contact with the ways of thinking of many disciplines and contexts such as research institutions, industry, and non-profit organizations. All graduates are expected to be **critical thinkers**. An **entrepreneurial mindset** is promoted in which students take initiative and have a problem-solving approach. For those who want to explore a career in science, the research groups on campus can serve as inspiration. The ample contacts and educational partnerships with the companies in our Brainport ecosystem will give the students who aspire to work in industry the opportunity to get to know their options. Students who want to explore their options in entrepreneurship can receive assistance in their explorations from experts on and off our campus, for example in TU/e innovation Space and in The Gate. Those who aspire to a teaching career have the opportunity to develop a teacher profile in parallel with their degree program or after graduating. The TU/e community offers them ample options to discover their talents through participation in a wide range of activities and (the boards of) organizations such as study associations and student teams.

All TU/e students are prepared for the international field of work by experiencing what it is like to work in an international environment during their studies. The diversity of the TU/e campus offers this opportunity, but in addition to this **all students are stimulated to experience what it is like to study and live abroad** and feel first-hand how this can help shape you as a person and as an engineer.

TU/e strives to make sure that all students who graduate have a clear idea of what their talents and aspirations are, and develop a growth mindset which will enhance their wellbeing as students[15] and as professionals, making them durably employable in the field of work they choose. Research informs us about the characteristics that make students durably employable16. At TU/e, we consider the following four elements as essential for students to have in order to attain durable employability:

- **Academic knowledge and field-related skills**

This aspect includes knowledge and skills related to the key concepts of the discipline and engineering profile that the program is aimed at. It also includes more general academic skills that a graduate needs to function in the engineering profession, such as analytical and system thinking, problem-solving by an iterative process of divergent and convergent thinking, information literacy, and dealing with ethical issues.

- **Professional skills**

This refers to the general skills required to function in a professional setting, like problem-solving, critical thinking, presenting, writing, time management, working in international and multidisciplinary teams, and dealing with different interests (stakeholders) and responsibilities.

Self- and social awareness
In order to be sustainably employable, students need awareness of their personal learning objectives, strengths, weaknesses, values and beliefs, including the ability to reflect on these. Reflecting on the own learning process and development is essential to gain insight and learning to give and receive (critical) feedback in a constructive way. This aspect also includes the ability to build and be a constructive part of relevant networks and teams, including international ones.

Adaptability
Being durably employable requires students to be able to actively prepare for, as well as adapt to, changing (professional) environments and circumstances. This includes personal initiative in study and career planning, as well as being able to learn and work in different environments and as such is a prerequisite for life-long learning.

These elements will be explicitly designed as a learning line in the TU/e programs, and students will receive coaching throughout their education at TU/e to help them come to a clear profile of who they are, what engineering profile best suits them, and how they can further develop towards their desired career. This will create the mindset of lifelong learning and development that makes them "future-proof" in a constantly changing world.

Learning in the innovation hub: our faculty, university and ecosystem

TU/e faculty

The changes expected will require the full use of the talents for educational innovation in our faculty. Their **teaching role will become more diverse**: in addition to transferring knowledge, the guiding and supporting role of teachers will become more prominent, as well as the task of designing and developing diverse learning activities and environments. Faculty will be seamlessly connected to students for the different learning activities. The teaching role will broaden from traditional lecturing to a diverse array of activities. Staff will combine expertise in their discipline with various didactic capabilities. Just-in-time learning will require more flexibility in teaching practice. Hybrid education will change the way lecturers and students interact, creative and innovative (digital) approaches can help in achieving this in a way that preserves the valuable contact between lecturer and student. **Personal leadership**, taking ownership of the development and improvement of learning activities and of their own didactic skills, is essential. To achieve this in an efficient way, **team teaching** will become the norm. The way we envision future education benefits from having a cross-functional team involved to share the workload and divide the different roles in developing, implementing and supporting educational activities. This will allow faculty and support staff to **pool their expertise and share responsibilities**, and demonstrate how multi-disciplinary teamwork can lead to innovation and excellence. **Making use of the strengths** of all involved will enhance both the quality of the education and the job satisfaction and wellbeing of the team members, while not having one person responsible for all elements makes **our curriculum more resilient** and may **alleviate work pressure**. We realize we expect a lot from our teaching staff in this innovation process, and they in turn can expect extensive and high-quality support in realizing innovation and managing workload. Developing knowledge and skills will take time and effort, and staff should have ample time for professionalization and innovation and be appreciated and **rewarded for their educational innovativeness and excellence. Monitoring and managing staff workload** will be a constant point of attention. Teaching capacity could be increased by involving fellows from industry in guiding the challenges, and by employing teaching assistants and senior students to take over certain tasks to free up our staff to innovate education. The importance of and rewards for designing and developing innovative education should be on par with those for developing and conducting innovative research.

We want to train our students to be life-long learners, and our faculty should lead by example. TU/e wants to **accommodate and support faculty to continuously develop in their role as teacher** and to keep up to date with the latest development in engineering education. A good educational support system should be in place, in which lecturers are in intense cooperation with pedagogical support staff who have didactic and digital expertise. In this way, knowledge and expertise can be optimally applied and shared. The educational support staff can also facilitate the exchange of knowledge within and between the departments.

Knowledge on educational and didactical topics will be bundled in the **Academy for Learning & Teaching (ALT)** for faculty which provides support in developing their didactical expertise, can be consulted on specific topics and will be a community in which knowledge can be shared and disseminated.

TU/e: the institution

TU/e is a research university: **research and education are naturally intertwined**, and students learn about the latest results and insights from innovative research projects. Students are exposed to scientific research methodologies and approaches throughout their study program. The way in which this takes place will gradually change as students develop through the different stages of their program. In the first stages of the bachelor program, students start with developing the critical academic attitude we expect from all our students. They learn to look critically at scientific information, and see this attitude demonstrated by their role-models, the teaching staff. This will rapidly develop towards more active participation in (parts) of the research process by students, and result in close collaboration between staff and students as partners in conducting innovative research. CBL will help to facilitate and integrate this, as elements of the research process are a natural part of tackling societal and technical challenges. Students will be introduced to a broad spectrum of research, ranging from very fundamental research questions to applied research projects. This implies that for TU/e staff, research and education are equally intertwined, which will also require equal acknowledgement of educational and research talent. The combined role of researcher and lecturer means that students get up-to-date information in their classes, see inspirational examples of research that is done at TU/e, and are coached by staff when they design and execute research projects themselves. In the ideal situation, the interwovenness of research and education will benefit both students and faculty: students are introduced to state-of-the-art knowledge and research techniques, while the work done by those students can contribute to the research projects of the staff, and bring new perspectives into research projects. We see this happening already in the honors program, which allows students to work on cutting-edge challenges while the teachers benefit from the input of our highly talented students, resulting in tangible results such as solar cars and sustainable houses.

As stated before, TU/e sees an important role for on-campus activities and cooperation in learning. The campus is a lively community, in which there is ample opportunity to collaborate. The focus of on-campus education is on active learning and intensive exchange. This has consequences for the **design and organization of the physical campus (i.e. the buildings) and the educational structure**. There will be less need for large lecture halls, more need for labs and workplaces to design prototypes, and also for flexible multi-purpose rooms where teams can collaborate. Enhanced flexibility and different ways of organizing learning lines may lead to changes in the structure of the academic year.

"If you allow the educational process to self-organize, then learning emerges" *– Sugata Mitra*

Visitors of the campus will be inspired by the innovative work of students and faculty working on challenges, development of innovations and cutting-edge research.

The theme of **sustainability**, as defined in the UN Sustainable Development Goals permeates the campus, the educational programs and the challenges that are taken on, making the TU/e campus ready for the future. Sustainability is already a highly important theme in TU/e research. By bringing it more and more into the challenges that students work on (as we already see happening) we enable our students to start contributing to a more sustainable future from the very beginning of their study program.

TU/e at the heart of the Brainport region

The TU/e is uniquely located in the brainport region, where innovative high-tech industry is represented by both large, well-known companies and small-scale innovative start-ups. This matches very well with the developments taking place at TU/e, and it is therefore not surprising that the TU/e has a long and extensive history of fruitful collaboration with its ecosystem, particularly in research. The field of engineering has seen a shift from focusing mainly on design and construction towards a focus on scientific research. It is important to strike a good balance between design and research, since engineering education includes both of these elements. For this, the cooperation and interwovenness of partners in the quadruple of education, research, industry and government are essential. The diverse eco-system of TU/e offers the ideal opportunity to optimize this cooperation.

We work closely together with other educational institutions in the Brainport region. With the universities of applied sciences we have multiple collaborations and projects to attract and retain students for the engineering field of work, such as forming a joint front in interesting students in secondary education in the STEM field, collaborating in student recruitment and in developing pathways and opportunities for Life Long Learning and Development. All to ensure that we optimally develop and deploy the available talent. The strong collaboration of TU/e with partners in its ecosystem will be further developed for education in the coming years, as the growth of Challenge-based Learning offers an ideal opportunity to intensify the cooperation. Faculty can **collaborate in partnerships**

with industry to develop the real-world challenges that students will work on, while industry can also have a more prominent role in education, for example by providing consulting for students while they work on these challenges and opening up in-company training and workshops for students. **Hybrid teachers** can already be found on the campus, and their number will grow, while their role in education will diversify. They can contribute to teaching teams from their unique perspective as linking pin between academia and the field of work. The innovative results developed at TU/e, for example in the open-ended challenges of CBL, should easily find their way into the brainport region.

The flexible and modular system will also make the TU/e more accessible for employees from industry who wish to update and deepen their knowledge and skills. The options of (micro)degrees based on a program of different modules can be explored, but the trajectories of EngD and PhD are also open to those who want to develop towards design and/or research. **Lifelong learning and development** will stimulate exchange between TU/e and the ecosystem.

TU/e collaboration with national and international partners

To enhance and stimulate innovation and efficiency, collaborating with strategic partners is essential. This not only applies to industry, but also to educational institutions. These interactions offer endless opportunities for collaboration and exchange, and will help us in developing the education of the future. On a national level, our ecosystem takes shape in the **EWUU alliance** of TU/e, Wageningen University, Utrecht University, and the Utrecht Medical Centre. This alliance of partners that represent complementary areas of expertise will allow all participants to broaden their scope and organize collaborations of very diverse disciplines. This discloses these complementary disciplines to our faculty and students, and enriches our education with the input of students from other disciplines. A shared focus on CBL ensures that our strengths in innovating education are bundled, and that we can experiment with collaborating on educational challenges on an interinstitutional level. The alliance is already taking shape and the collaboration will further intensify in the coming years. On an international level the **EuroTeQ alliance**, an education-specific part of the broader EuroTech alliance, enables us to bundle our strengths with like-minded and comparable European universities of technology. In this alliance we explore the multiple options for international collaboration with a shared vision on education engineers of the future. It brings an international and intercultural perspective on our disciplines, and allows students and faculty to experience working in an international environment, both virtually and physically. We will learn about organizing green (virtual) mobility that still makes students feel part of the community. The European grants that were awarded to the EuroTeQ alliance have allowed a flying start of our collaboration with regard to education, and this will only grow in the coming years.

The strategic partnerships and alliances build on our strengths and can help us in many ways to work towards our goals.

TU/e is embedded in Brainport, a unique, innovative high-tech ecosystem

Developing towards future TU/e education: a learning organization

The changes in the field of engineering and in education mean that the TU/e will live through a period of change in the coming years. We will take significant steps in further developing our way of educating, incorporating the strengths we have and the lessons we have learned during the last few years in which the COVID-19 crisis forced us to demonstrate just how agile and innovative we are. Developing towards the vision of education described in this document will **make us more resilient** to future comparable disruptive events: more flexible and diverse ways of offering education and smaller groups will limit the effects of measures such as the lockdowns that we lived through in the COVID-19 pandemic.

In the coming period, we will be learning and developing together to achieve the education we envision. In our approach to this development, we will "practice what we preach". Just as we expect of our students, we want to be a learning organization that experiments with innovations, learns from its own experiences and those of others, and constantly reflects on these experiences in order to shape the next step in our development. This also means that the picture of TU/e education will gradually become clearer and sharper along the way.

Central structures will help us to efficiently exchange and disseminate the knowledge we gain in this process. We have taken important steps for this already. Several programs are instated to coordinate and stimulate developments in different areas, such as CBL and digitalization (BOOST!). Closely monitoring and evaluating the different experiments will help us come to an evidence-based way of working. TU/e innovation Space plays an important role in this, as several educational awards and grants have enabled substantial research projects into CBL. The TU/e Honors Academy

provides a breeding ground where innovations can be tested outside the curriculum. Evaluating and reflecting on the outcomes of all the different experiments is of vital importance to grasp how the key concepts of CBL work, for example assessment and student ownership. A community of researchers has taken shape in which all research results regarding CBL and related themes are exchanged. A community of practitioners is also growing in which the experiences can be exchanged, involving staff of all departments and services to optimize sharing of best practices on topics such as design, development, practical conditions, assessment, and evaluation. The Academy of Learning and Teaching will have a pivotal role in building a community and culture promoting high-quality and innovative teaching. With more recognition and rewards for teaching excellence, the community of inspiring examples grows. Already TU/e has several (inter)national prize-winning teachers who can inspire and lead others in innovating education, for example Isabelle Reymen, Johanna Höffken and Reinoud Lavrijsen. An **essential role is of course reserved for the departments and programs**. They have already demonstrated their capacity for innovation by designing and conducting numerous experiments, and in the coming year those changes will move to the curriculum level. The developmental trajectories may differ between the programs, as each has its own characteristics and points of attention for the transition process. To help them, a **well-organized educational support service geared towards innovation** is key. The experiments in the first stage of our development were mainly done at the course-level, and based on the results from these experiments, the next iterations will be aimed at **changes on a curriculum level**, combining the different elements from CBL and diverse learning paths in parallel, and in a coordinated way. In this stage, we need to test and develop the ideal combinations of the different elements, how they can be interwoven to optimize learning, and how we can support students in self-directed learning, finding their way and shaping their learning trajectory. Will students be able to take the lead in shaping their learning path, and how can we optimally support them in this process? As more and more students go through this process, we will be able to optimize the way in which curriculum and learning activities are presented, organized and offered. The scale, complexity and integration of elements will grow as we go through subsequent iterations. Constantly learning from the experiments and experiences, supported by a **well-organized quality assurance cycle**, will help speed up the development towards the envisioned outcomes. The cycle of further evaluating, developing and optimizing TU/e education will not stop there, since TU/e truly is **a learning organization**. The CBL way of working enables the TU/e to adapt to the latest societal and technological developments in a swift and flexible way.

"Engineering education is entering a period of rapid change" – *Ruth Graham*

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